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NUCLEONICS

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Vol. 10, No. 12

WORLD PROGRESS IN ATOMIC ENERGY... 7
A NUCLEONICS Special Report

Determining Neutron Fluxes from a Pulsating Radiator... 36
ALLEN BRODSKY

Progress Report on Industrial Nuclear Power... 40

Use of Fission Products for Insect Control... 42
CHARLES C. HASSETT and DALE W. JENKINS

Assay of Mixed Radioisotopes... 47
J. F. TAIT and E. S. WILLIAMS

Storage of Radioactive Gases from Reactor Operation... 52
RAYMOND L. MURRAY

Use of Palladium-109 as a Multicurie Beta-Ray Source... 54
W. W. MEINKE, A. H. EMMONS, and J. V. NEHEMIAS

Activation Assaying for Tantalum Ores ...58
G. G. ECHHOLZ

Graphical Analysis of Cloud-Chamber Photographs... 62
J. S. CAMPBELL and D. F. WELCH

Cobalt-60 Irradiation Chamber... 65
M. A. GREENFIELD, L. B. SILVERMAN, and R. W. DICKINSON

Performance of Lucite-Bonded Alpha-Scintillation Screens... 68
J. D. GRAVES, L. A. WEBB, and R. H. DAVIS

Cross Sections

Small Corrosion-Resistant Valves for Remote Chemical Service... 72
GERALD J. SELVIN

Radioactive Building Tiles... 73
W. H. HOATHER

Scintillation-Counter Safeguard for Co^{60} Source... 74
JACOB E. DIETRICH and WILLIAM R. KENNEDY

Nomogram for Computing Register Losses... 76
WILLIAM C. DAVIDON

Departments

BOOKS..... 78
NUCLEONIC EVENTS..... 82
PRODUCTS AND MATERIALS.. 88

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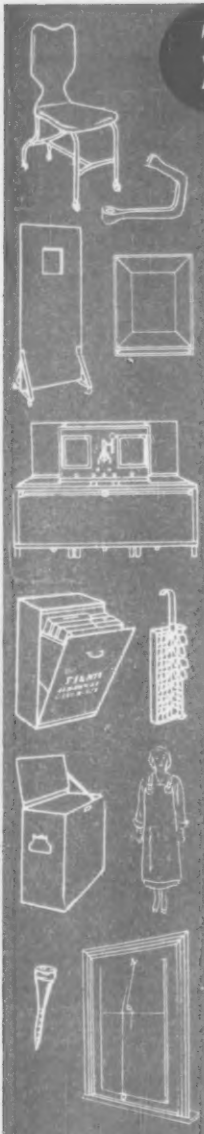
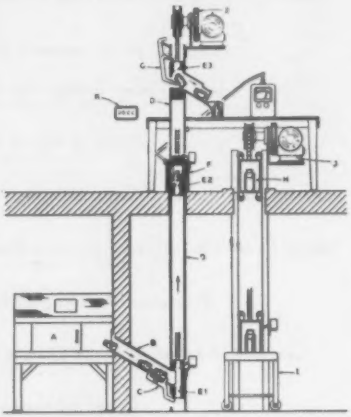


RADIOISOTOPE CONVEYOR SYSTEM

This radioisotope conveyor system was constructed and installed by Bar-Ray for the Francis Delafield Hospital. The system was based on the design by C. B. Braestrup, Physics Laboratory, Delafield Hospital and engineered by the technical staff of the Bar-Ray Company. The measuring system was built by the physics staff of the hospital.



This conveyor system provides for the transfer of isotopes from the sub-basement to the floor above by remote control.

The preparatory work is done in a lead-lined hood (A). The isotopes are then labeled, placed in bottles, set in device (C) that prevents the bottles from entering the vertical tube.

The vertical tube (D) houses a lead dumbwaiter (E) so designed that when the dumbwaiter is dropped to its lowest position (E1) it actuates the holding device (C) and allows one bottle to enter the dumbwaiter. The action of this holding device is such that all other bottles in the tube (B) are held up until the dumbwaiter is raised, after which the next bottle is automatically placed in position ready to drop into the dumbwaiter.

The dumbwaiter is then raised and, on the way to the upper floor, the isotope passes through the center of an ionization chamber (F) where it is stopped automatically at position (E2) for gamma-ray measurement. The dumbwaiter is then raised above the level of a work counter at position (E3) where the bottle is automatically ejected from the tube (D) by a spring loaded mechanical arm (G) and drops into a lead container. It is then temporarily stored or taken at once to the treatment room.

The empty bottles are returned in the large dumbwaiter (H), which also has the function of transferring isotopes, in the lead container from Oak Ridge, to the sub-basement labs or storage area. A carriage (I) is provided for readily moving the heavy Oak Ridge containers from the large dumbwaiter to the lead-lined hood.

Both dumbwaiters are motor operated (J) and are controlled from the upper floor at a push button station (K) with limit switches provided for the various stops.

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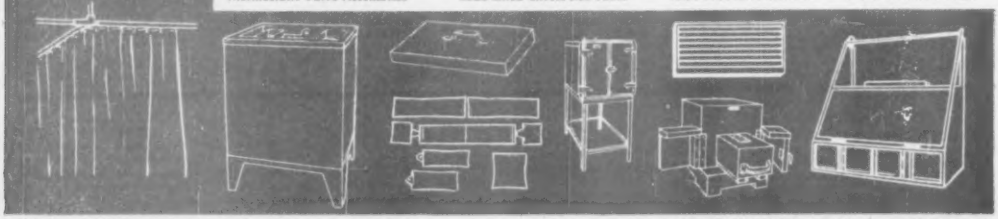

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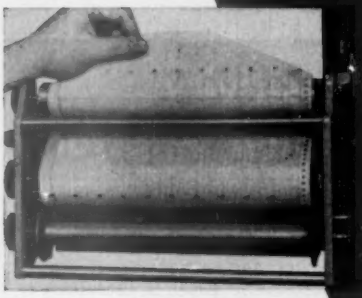

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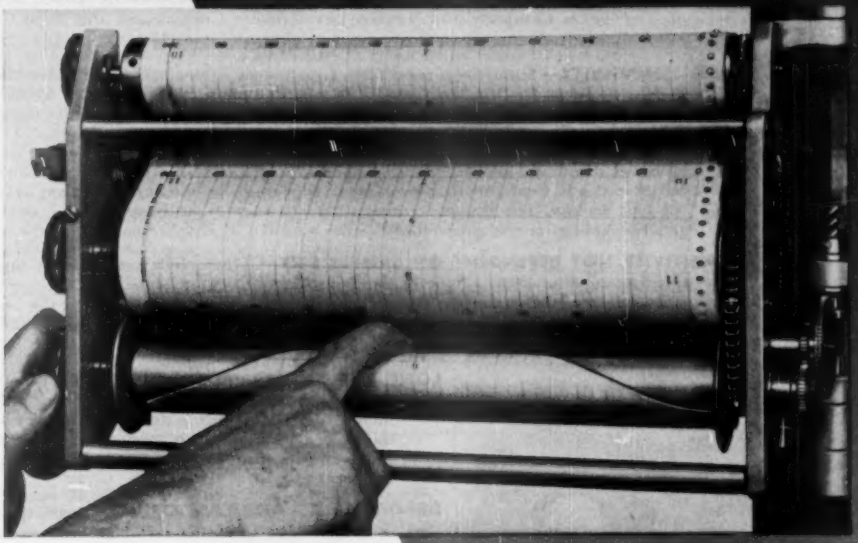

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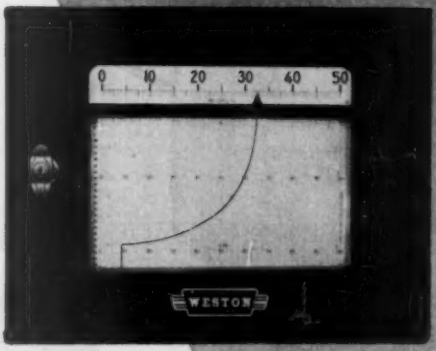

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LONG LIFE AND STABILITY—The Type GR counter is exceedingly stable and, due to a special type of gas filling, has an infinite life. The counter is structurally sturdy and can stand unusually rugged use. Inadvertent over-voltage, which often results in permanent damage to other types of counters, will not harm it.

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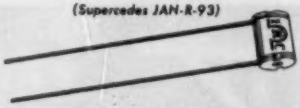
TYPE BW INSULATED WIRE WOUND RESISTORS ½ and 1 watt inexpensive wire wound resistors for low range requirements. Small and completely insulated. Wire resistance element is uniformly and tightly wound on an insulated core.	JAN-R-184 *(Characteristic B)*
NEW TYPE BOC BORON-CARBON PRECISTOR ½ watt. Latest development in stable film-type resistors. Combines high accuracy and long-time stability. Reduces temperature coefficient of conventional deposited carbon resistors. Replaces high value wire wounds at substantial savings in cost and space. Essential in critical electronic and avionic circuits.	MIL-R-10509A Specification
TYPE DCC DEPOSITED CARBON PRECISTOR ½, 1 and 2 watts. Latest advance in small-size, high stability resistors. Ultimate in non-wire-wound accuracy. Stable over long periods. Assures low voltage coefficient, low capacitive and inductive reactance in high frequency uses. Efficient and economical in modern electrical and electronic circuits.	MIL-R-10509A Specification *plus latest JAN Specification Proposal*
TYPE WW PRECISION WIRE WOUND RESISTORS Severe cycling and 100 hour load tests result in almost no resistance change. New winding forms hold more wire for higher resistance. New winding technique eliminates shorted turns. New type insulation withstands humidity. New terminations are rugged, strain-free.	MIL-R-93A Specification *(Supercedes JAN-R-93)* 
TYPE MF SEALED PRECISION VOLTMETER MULTIPLIERS Completely impervious to humidity. Interconnected precision wound coils are encased in glazed ceramic tube—hermetically sealed. Multiple-layer windings insure resistor against breakdown. Compact, rugged, stable, easy to install.	JAN-R-29 Specification
POWER WIRE WOUND RESISTORS For exacting, heavy-duty applications. Exceptional mechanical strength; withstand severe vibration. Available in two coatings; a variety of ratings, sizes and terminals; fixed and adjustable types; tubular or flat.	 TUBULAR PWW'S —JAN-R-26A *(G and J Characteristics)* FLAT FRW'S—Correspond to JAN-RW Types

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Operator at Atlantic Refining Co., inserts alpha detecting phosphor by lifting chimney containing 5819 photomultiplier tube. Using different phosphors the G-E Scintillation Counter can also detect beta, gamma, and thermal neutron radiation.

Using a G-E Scintillation Counter to determine beta radiation, The Atlantic Refining Company, Philadelphia, has a new method for measuring the adhesive quality of asphalt which determines the degree to which a road holds together.

This is the test method used: Crushed paving stones are soaked in radioactive calcium chloride solution and dried. The stones are then coated evenly with asphalt, which may contain additives to improve its adhesive characteristics. This mixture is covered with water for a definite period of time.

If the asphalt separates from the stones, the radioactive calcium chloride will dissolve into the water. When the water is evaporated, radioactive residue will remain. The amount of radioactivity is measured with the G-E Scintillation Counter, indicating the resistance of the stone and asphalt to deterioration by water.

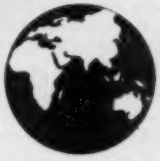
Here is a typical example of how industry can make use of the by-products of atomic energy with the help of special instrumentation developed by General Electric.

For more information about this and other G-E Radiation Instruments contact your nearest G-E Apparatus Sales Office, or write for Bulletin GEA-5735 to General Electric Co., Section 687-105, Schenectady, N. Y.

Radiation Detection Instruments

GENERAL ELECTRIC

World Progress in Atomic Energy



THE DISCOVERY, development, and application of the forces of nuclear energy have followed a chronology oft-repeated in modern-day technology. The basic facts were unearthed by individuals in widely scattered laboratories. Over the years, various pieces of information fell nicely into place in a neat pattern. Then, suddenly, an urgent demand for a "finished product" concentrated and telescoped scientific activity so that an end-use came about in a shorter than normal time. Apart from the end-use sought, the fruits of this concentrated effort are expected to result in many benefits not yet clearly defined.

This, in capsule form, is the course which nuclear-energy developments have run to date. In 1789, uranium was first isolated by a German. In 1939, the fission of uranium was discovered by two other Germans. Between these two dates, significant contributions were made by scientists from England, France, Italy, Denmark, the U. S., and Germany.

It was the discovery of fission in 1939 which led to the setting up in this country of a mammoth project for the development of an atomic bomb. Very early in this project—December 2, 1942—an event occurred which may yet have an impact on human endeavor greater than any other scientific achievement. This was the world's first self-sustaining nuclear chain reaction, the scene of which was the University of Chicago.

This feat, made possible by the groundwork laid by men of many nationalities, is already, in fact, having significant effect on the scientific activities of many countries throughout the world.

To commemorate the tenth anniversary of this "birth of the atomic age," the Editors of NUCLEONICS have prepared a special report on "World Progress in Atomic Energy." We have sought to assess the impact on the world of the events of December 2, 1942. To do so, we have looked back at developments in the past decade. More important, we have looked ahead to the next decade.

This report covers the atomic energy programs of fifteen countries in Europe, North and South America, and Asia. [Because NUCLEONICS has devoted most of its pages in the past to reporting on progress and future trends in the U. S. atomic energy program, we are omitting a description of it here.] The material was collected for us by McGraw-Hill World News correspondents in each of the countries.

We asked these correspondents to give us a progress report on, and a look into the future of, atomic energy work in their countries. We emphasized that we were not interested in the military aspects of atomic energy. Rather we sought answers to questions such as these:

1. What were the most significant technical developments in the atomic energy field in your country in the past decade?
2. What emphasis, if any, or expected direction is planned for scientific and engineering work in the atomic energy field during the next decade?
3. What attitudes exist toward the technical significance of atomic energy?
4. What is being done, and what is planned, in the field of nuclear reactor technology?

In addition, questions were asked about the country's organization and staff for atomic energy work.

Our correspondents have come up with a report which shows that:

1. Thirteen of the fifteen countries will possess one or more nuclear reactors within the next decade.
2. Shortage of conventional energy resources in these countries makes nuclear power very attractive.
3. Regardless of the size of the countries, money is being found to exploit this field.

However, because the tools of atomic energy work come big, the principal deterrent to large-scale programs has been the unavailability of large sums of money. At the same time, very few countries in the world have "more than enough" uranium. These two factors have resulted in cooperative programs among many of the countries.

Two such programs stand out. One is the Norwegian-Dutch Joint Establishment for Nuclear Energy Research centered about a reactor operating in Norway. The other is the just-formed ten-country European Council for Nuclear Research which will revolve around several large particle accelerators to be built in Switzerland.

These programs are of particular interest because they are resulting in a sharing of information which is unprecedented in the atomic energy field. They are showing and will show even more forcefully that the secrets of nature cannot be locked up by any one nation.

EUROPE . . .

A large laboratory, with cosmotron and synchrocyclotron, will soon be erected near Geneva. In it, the scientists from ten European nations will work on a coordinated program of research with a collection of equipment that no one of these countries could afford if working alone. Such is the goal of the European Council for Nuclear Research

THE IDEA of bringing together small European nations to pool their funds, knowledge, and enthusiasm for nuclear research was brought before the 1950 General UNESCO Conference in Florence, Italy, by the American physicist, Isidor I. Rabi, of Columbia University. It caught on quickly. Under the leadership of France's Prof. Paul Auger, plans were promptly drawn up for an organization meeting of the interested nations, and the European Council for Nuclear Research was born.

At Geneva, in February, 1952, ten nations signed a convention creating the Council: Belgium, Denmark, France, Germany, Italy, The Netherlands, Norway, Sweden, Switzerland, and Yugoslavia. Greece and Great Britain sent observers to the meetings, but there is no indication that these nations will become members.

A provisional fund of over $200,000 was set up by the member nations to finance the scheme in its first planning period, expected to last about a year. After that, more funds (probably about $25,000,000) will be required to finance the building period, which will take five or six years.

On October 4–7 this year at Amsterdam, the Council decided upon its three most important building projects: (1) What it calls "the world's largest laboratory for nuclear physics," to go up on a site near Geneva, Switzer-

Switzerland . . .

With Geneva the site of the European Council's laboratory, Switzerland will become the hub of continental nuclear research. Apart from Council work, the Swiss expect to build their own research reactor

ZÜRICH—Switzerland recently revealed that it has plans to build a heavy-water research reactor.

Although one of the first nations in Europe to recognize the national importance of atomic energy for peacetime use, Switzerland has been delayed in its efforts to develop an extensive program of research because it has no access to uranium or thorium. According to W. Zünti, Zürich physicist, "no significant uranium-ore deposits have been found in this country." This, plus the fact that Switzerland has found it almost impossible to purchase fissionable material from other countries has, Zünti says, considerably "affected the extent of basic research in nuclear physics and related fields at all the Swiss universities" in the past decade.

In 1946, Switzerland named a national advisory committee on nuclear energy [Studienkommission fur Atomenergie (SKA)], with Prof. Paul Scherrer as chairman. Prof. Scherrer, who has served as chairman of the new European Council for Nuclear Research, also directs the nuclear physics program at the Federal Institute of Technology, Zürich, where the majority of Swiss nuclear research is done. Six universities—Basle, Berne, Geneva, Lausanne, Neuchâtel, Zürich—also have programs in progress. The equipment at these centers includes several particle accelerators.

SKA, the Swiss say, is and always has been quite aware of the great potential peaceful possibilities of nuclear energy, and so are the leading Swiss mechanical and electrical-engineering companies. In a joint effort, they plan to build a heavy-water reactor. Right now there are a few obstacles to overcome, but it is their hope that their project will be realized "in the near future."

In the meantime, as host nation to those who will work in the European Council's Geneva laboratory when it is built, Switzerland will have a rare opportunity to broaden its own base for atomic-energy developments.

land; (2) a 30-Bev cosmotron; and (3) a 600-Mev synchrocyclotron.

Laboratory and Staff. Denmark, France, The Netherlands, and Switzerland offered sites for the establishment of the central laboratory. The first three countries generously withdrew their proposals so that the Geneva site could be unanimously chosen since it seemed to offer many advantages over the others. It is a plot of 100 acres near plane and rail connections. It also offers an ample supply of multilingual technicians and inexpensive electricity.

The laboratory will have a staff of 500; of these, 50 will be permanent-staff scientists and 100, visiting scientists.

Four study groups. During a conference this past May, in Paris, four study groups were appointed.

The first group, headed by Mr. Odd Dahl of Norway, was entrusted with investigating the construction of a 10-Bev cosmotron. Originally, this group was considering a design like that of the 3-Bev machine at Brookhaven National Laboratory. With the new strong-focusing principle recently worked out at Brookhaven (NU, Nov. '52, p. 106), however, it now seems sensible to the group to use this principle in their design. This means the magnet of the machine can be much smaller than that of Brookhaven's present cosmotron, and the energy higher. Since the magnet accounts for the major cost item, the estimated building cost of $14,000,000, which the group was figuring on, will permit the construction of a cosmotron of a much higher energy. The group is now investigating a 30-Bev design.

The second group, under the direction of Prof. C. J. Bakker of The Netherlands, is looking into the construction of a 600-Mev synchrocyclotron, with a 5-meter pole diameter and a 2,500-ton magnet. They are also studying new high-frequency modulation systems. This accelerator will cost about $4,000,000 and take four years to build.

The third group, with Dr. L. Kowarski of France as leader, is planning the organization of the laboratory.

The fourth group, under the lead of Prof. Niels Bohr of Denmark, will conduct theoretical studies and will plan coordination of the work of European laboratories involved.

A reactor for Geneva? Several European scientists think the Council should consider building a nuclear reactor, but they must contend with the misapprehension of others who are afraid of including reactors in the European cooperation scheme because of the political superstition that they are necessarily military instruments. Those for the idea say there is no reality to the belief that research reactors could cause political difficulties, and they argue that a modern nuclear physics laboratory is incomplete without a strong neutron source.

The Council's future. Development of Europe's cooperative nuclear research laboratory is thus under way. The results of Geneva research will be available to everyone. As for the future of the European Council for Nuclear Research, plans are that, on completion of the Geneva laboratory, the Council will be dissolved and replaced by a new body.

Belgium . . .

As principal uranium supplier to the western world, Belgium has an understandable interest in atomic energy development. The country is in the midst of putting some large machines for nuclear research into operation and is designing a reactor

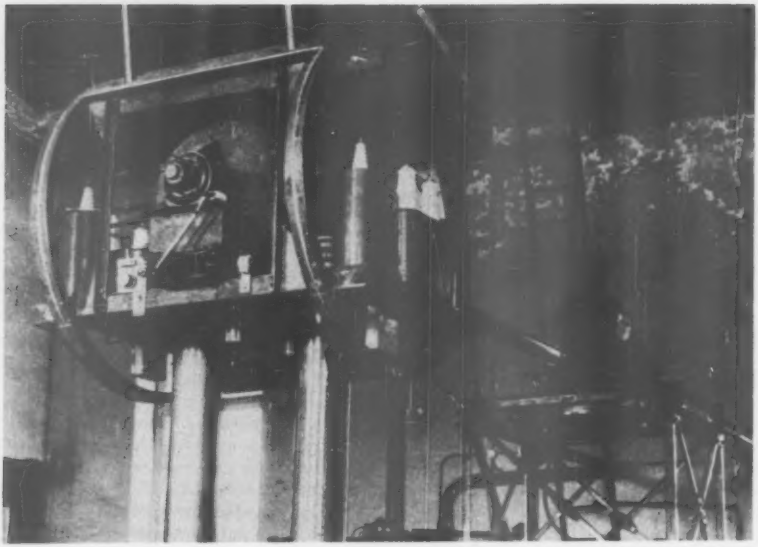
BRUSSELS—Belgium has a broad, coordinated program of research and development planned for the next decade, with one of two proposed reactors to be built in 1953.

The first of the two reactors will be a small one, on the type of the CP-2 (Argonne) or GLEEP (Harwell), both graphite-uranium reactors. It will probably be erected not far from Brussels and will be used mainly for research. With this reactor, Belgium will no longer have to depend completely on radioisotopes imported from the United States and Great Britain. Plans for the reactor are expected to reflect some of the knowledge and experience gained from a long study-visit of eleven Belgian scientists to Argonne National Laboratory in the United States.

The second reactor, still five or six years away, will be a bigger affair, probably costing about $20,000,000. No design or site for it has been decided. However, it is hoped that it will be a power reactor.

Belgium has a special interest in nuclear science, one of

DE HEMPTINNE examines Belgium's only cyclotron, a 30-Mev accelerator at the Catholic University of Louvain



AT LIÈGE, unique generator, using Pauthenier principle, produces 1 ma of 1-Mev particles. Acceleration charge is carried to collector (shown here without aluminum casing) by air stream of small glass particles that first passes through ionizing units. Bakelite ducts for air-and-glass stream were recently replaced by 10-foot-long tubes of brown wrapping paper because static charge split the plastic tubes

the principal reasons being that the uranium mine at Shinkolobwe in the Belgian Congo is the western world's biggest supply source. The Union Minière du Haut Katanga, a copper producer, owns the Shinkolobwe mine and is deeply interested in aiding development work in the field. The Belgian-made magnet of a newly-installed 30-Mev cyclotron at the University of Louvain, for instance, is a gift from this company.

Belgium also possesses one of the world's most modern plants for the extraction of radium from the Congo ores. It is owned by the Société Générale Metallurgique de Hoboken, and located at Oolen (near Antwerp). The plant receives the ore after it has first been processed in the United States for extraction of the uranium.

Areas of Responsibility

Nuclear studies have had great impetus in other countries since World War II, but they are not new to the Belgians. The new cyclotron at Louvain, for instance, which was erected only this year, was ordered the day before the Nazis invaded Poland in 1939. What has resulted in Belgium from the postwar impetus, however, is an organization of these studies on a national basis.

Inter-University Institute. An Inter-University Institute for Nuclear Research serves to coordinate and, to some extent, plan (but not direct) the work in four of the country's universities and in the Royal Military School. Liège, Louvain, Brussels, and Ghent are the member universities. The Institute chairman is Jean Willems, who is also director of the National Research Foundation.

Study Center. The two proposed reactors, when built, will not come within the orbit of the Inter-University Institute. They will, instead, be sponsored by the Study Center for the Application of Nuclear Physics, a body aimed at combining the academic, industrial, and governmental interests. A council, responsible for the Center, has as its chairman former Congo Governor Pierre Ryckmans, a member of the Trustee Council of the United Nations and colonial advisor to the Belgian delegation. The council consists of representatives of mining interests (Union Minière du Haut Katanga) and industry (Belgian Union Chimique group and the Ateliers de Construction Electrique de Charleroi).

It is hoped that the Center will, in due course, receive funds from industrial and other sources, apart from the government. At present, both the Institute and the Center are government-financed. The main financing work of the Center is yet to come. The Institute, however, has for some time acted as the middleman in distributing government-contributed research funds. The only provision made for it in the budget is $700,000, carried annually in the Ministry of Public Instruction vote, but it is understood that there are substantial sums outside the budget which the government is able to bring in for this purpose.

The Past Decade's Work

Three things, Institute members say, stand out in Belgium's achievements over the past ten years:

First is the technique developed at the University of Brussels for producing pure uranium in the metallic state. Still only in the laboratory stage, the work has yielded several hundredweight from the two tons (metal equivalent) of ore available.

Second is Belgium's contributions to nuclear-plate and emulsion techniques. The feeling in Belgium is that it

can now claim at least to share with England the world leadership in this research. The Belgians point not only to the world-famous work of Brussels' Prof. G. Occhialini but also to the important work being done by Liège's Prof. Max Morand (formerly of the Sorbonne) and his assistant Leon Winand.

Third is the completion of the nuclear research laboratory at the Catholic University of Louvain.

Louvain

Isotope research is the main activity of the new laboratory at the University of Louvain. The work is directed by Prof. Count Marc de Hemptinne and two assistants, Paul Caprin and Jean Delfosse. With junior scientists and technicians, the staff numbers 35.

The largest of Louvain's basic tools are new this year—a 30-Mev cyclotron, mentioned earlier, and a 1.8-Mev pressurized Van de Graaff generator.

Liège

Like Ghent, Liège is a state university. Unlike Brussels and Louvain, it lacks the separate endowment funds which can be tapped for special researches or key equipment. It thus depends to a major extent on the Inter-University Institute for allocations of state funds.

The work of Morand and Winand at Liège includes the study of cosmic-ray plates exposed, in particular, at Karisimbi (Belgian Congo, 15,000 feet), Costermansville (Belgian Congo, 5,000 feet), the Jungfraujoch (Switzerland), and other points as far afield as the equator and inside the arctic circle. Special studies have been made of the east-west asymmetry in single tracks, and a further study is in progress on the relationship of altitude to the number of disintegration prongs. The work on nuclear emulsions includes studies of the Herschel effect on alpha-particle tracks, the "print-out effect," and the effect of humidity on the stopping power of emulsions.

In another department at Liège, Prof. Gueben, a specialist on neutron absorption, is continuing researches in that field. His assistant, Jean Govaerts, is working on tracer techniques and the problems of using radioisotopes for therapeutic purposes (in collaboration with the medical and biological faculties). His first important work was the preparation of radiophosphorous from carbon bisulfide. During World War II, he was able to continue his work on P^{32} and Ca^{45} with the aid of material smuggled through the enemy guards from the electrical laboratories of the Philips group at Eindhoven, Holland.

Liège also has a Cockcroft-Walton accelerator, built largely by the Philips organization, that will be ready for operation before the end of 1952. It will be used mainly for radioisotope preparation and neutron research.

Funds from the Inter-University Institute have been promised for erection of a Van de Graaff accelerator unit with a capacity of 3 Mev. Hitherto the only high-potential generator available at Liège has been a unique and highly successful one involving an adaptation of the Pauthenier principle.

Brussels

The nuclear research at the University of Brussels is under the general charge of Prof. Max Cosyns, who has very energetically supported the building up of a nuclear-plate laboratory by Occhialini. This laboratory is divided into three sections, one working on new techniques, one on cosmic rays, and one on radiogeology.

Nuclear-plate work. The aim of this group has been to make the photographic plate an instrument of precision for measuring very-high-energy particles. In this its success has been outstanding. Thick emulsions are needed, and the technique in Brussels has been standardized on an emulsion thickness of 1.2 mm for regular work, and 2 mm for special purposes. The reduction of distortion to a very low level has enabled the measurements of energies up to 10^{12} ev. A special method of measuring the distortion has been devised at Brussels.

Cosmic-ray work. This laboratory has been foremost in promoting the idea of scientific collaboration on cosmic-ray work with other universities, the sharing of techniques and plates, and the collaboration of young scientific workers in different centers. Though difficulties were to be expected, the success has been remarkable. Researchers in different countries have been able to work together, pool their experience and methods of measurement, put their results together, and publish them jointly.

Radiogeology. In the department of radiogeology, Dr. Picciotto, a geologist and chemist, has concentrated on examination of the radioactivity of rocks by the nuclear-plate method. His section is also working on age determination of the earth by the radioactivity method.

Other activities. Among the equipment at Brussels is a Philips generator with an accelerator tube. This is used mainly in research on low-energy particles being done by Prof. Henriot.

The metallurgical department (Profs. Decroly and van Impen) has brought the recovery of pure metallic uranium from uranyl nitrate to a point where, when the reactor to be built creates the need, industrial production methods can be quickly applied.

The same applies to a procedure developed at Brussels for the production of pure graphite for use in the reactors. It is still not known whether the procedure, which starts from methane gas, will be the one finally adopted, or whether the graphite needed for the first reactor will be bought from England. Nevertheless, the Brussels process is ready for industry to make use of it when needed. A number of graphite bricks have already been made in the Brussels laboratories.

Ghent

Work on graphite production has been going on too at the University of Ghent, under Prof. J. L. Verhaeghe, who has also been conducting research on neutron absorption.

Tools and the Future

Research with cosmic, high-energy particles is on a more settled basis than that with lower-energy particles in Belgium. This is a situation resulting from the fact that tools needed by the engineer and applied scientist for the latter studies have taken some time to provide. With the exception of the Pauthenier generator at Liège, Belgium's accelerators are all new and, in several cases, not yet in operation. When they begin operating, the emphasis will most likely switch to research with the lower-energy particles.

France . . .

"The beginnings of a network of nuclear-power plants by 1967" is the expressed hope of the French, who recently launched a systematized plan for future nuclear-development work. A second reactor went into operation in France two months ago

IRENE CURIE operating controls of Chatillon reactor. Looking on is Francis Perrin, head of France's AEC (center), and Maurice Surdin, electronics chief (left)

PARIS—France has embarked on the first of a series of five-year nuclear research and development programs aimed at the specific goal of exploiting atomic energy as a source of power on an economically sound basis.

The cost of the program drawn up by the government of Premier Antoine Pinay and approved by the National Assembly last July is 37.7-billion francs ($108,000,000) for the first five years. It represents an important advance for France whose total expenditure for nuclear development between 1946 and 1951 was only about 15-billion francs ($43,000,000).

Prof. Francis Perrin, head of the French Atomic Energy Commission, described the five-year plan in an interview with NUCLEONICS as the first phase of a 15-year effort that the Commission hopes will supply France with at least the beginnings of a network of nuclear-power plants by 1967.

Three Five-Year Plans

Perrin said the first five-year plan now getting under way will provide funds for the construction of two new primary reactors using uranium to produce plutonium. It will also include plans for training additional personnel in the field of nuclear physics and allow an expansion of uranium mining and prospecting activities in France and the French overseas territories.

A second five-year plan to follow will emphasize the construction of secondary reactors working from plutonium and the erection of pilot plants for the production of nuclear power. The third five-year plan, it is hoped, will see the actual construction of nuclear-power plants capable of commercially sound operation.

Perrin, who taught at Columbia University in 1940 as a visiting professor of physics, said the decision to direct the French atomic research and development program toward the goal of creating a new source of power—ignoring the military applications of atomic energy—was forced on the French AEC by the facts of France's economic situation.

"With the money available to us," Perrin said, "we decided it would be meaningless to try to produce atomic weapons. On the other hand, it was quite clear that development of a new source of power would be of great importance to France. So all our effort has been in that direction."

"Of course," he added, "all such decisions are subject to periodic review."

The fact that France, alone among major western nations, suffers from a serious chronic shortage of power was an important factor in the decision. France produces almost no petroleum and only about 70% of the coal she needs. A big hydroelectric power development program is under way, but, with the country's growing power requirements, it is unlikely that the increased production of electric power will substantially reduce France's need to import about 20,000,000 tons of coal annually.

"Some of the coal France imports—the part that comes from the United States—costs $26 a ton," Perrin pointed out. "That makes expensive power, and it means that we can produce atomic power on an economic basis to cover that high-cost marginal part of our needs long before atomic power is a commercially sound proposition in the United States or Great Britain."

Chatillon Pile

France's nuclear development program is just now beginning to move. The French Atomic Energy Commission started work from scratch and on a very small scale soon after the end of the war, but it was not until December 15, 1948, that they achieved their first chain reaction in the 5-kilowatt reactor ZOE at Chatillon near Paris. In the time since then, ZOE, a research reactor, has produced a total of about one-tenth of a gram of plutonium.

Saclay Pile

The second French reactor, at Saclay 20 miles southwest of Paris, was put into operation at the end of October. Known as P-2, the Saclay pile is a 1,500-kw heavy-water reactor that will be capable of producing 300 to 400 grams of plutonium per year when it gets into full operation. The amount of plutonium that it can produce can be higher or lower than this figure, depending on how the reactor is used. Plutonium production at Saclay will be secondary to isotope production and research.

An interesting feature of the new reactor is its unique cooling system. More efficient than other types, according to the French, it uses nitrogen gas, compressed to ten times atmospheric pressure, as the cooling medium. More power per ton of uranium is the result. By comparison, the Saclay reactor, they say, is expected to produce 400 kw per ton of uranium; similar reactors in the United States yield only 100–200 kw. Additional details appear on page 84.

With the second reactor going, France expects to be self-sufficient in radioisotope production in another year. The Saclay laboratory is the French equivalent of Brookhaven National Laboratory in the United States. It is principally a research center, where effort is being concentrated on work in the field of metallurgy. The equipment at Saclay includes a 25-Mev accelerator.

LEO KOWARSKI: In charge of all reactor development in France; he directed construction of Canada's heavy-water pile "Zeep"

JULES GUERON: Director of Saclay laboratory, location of France's second reactor which was put into operation recently

New Center in Plans

Two additional reactors will be built under France's five-year plan. No sites for the new installations have yet been selected, but it is probable that they will be located at a new nuclear-research center near one of the big hydroelectric power developments in the southern part of France where there is a sure and plentiful supply of electric power and water.

If the present tentative plans work out, this southern research center will be France's "atomic city." Along with the two reactors, there will be two small or medium-sized accelerators and a variety of laboratory equipment. The center will also include housing and other facilities for the personnel employed there.

Expanded Mining Operations

The first five-year plan provides for funds for additional uranium mining and prospecting. France now produces all the uranium it needs for nuclear research, most of it coming from a rugged section of central France. Mining operations there will be expanded, and new prospecting will be carried out in other areas of France and in French Morocco, French West Africa, French Equatorial Africa, and Madagascar.

More Personnel Needed

The second goal of the five-year plan is to provide a flow of competent personnel—scientists, engineers, and technicians—to meet the needs of the growing program. The plan provides funds to set up advanced courses in the nuclear sciences and to broaden training in physics and chemistry at universities and technical schools.

At present, the French Atomic Energy Commission employs 1,200 persons, of whom about 250 are qualified engineers and scientists. These figures do not include employees of the uranium mining and prospecting department. This staff will be increased about 20% each year under the five-year plan. Next year the Commission expects to add about 250 new employees, of whom some 50 will be engineers and scientific personnel.

A staff of capable men directs the work of the Commission under Prof. Perrin. Bertrand Goldschmidt is head of the chemistry department; L. Kowarski is in charge of reactor development; J. Gueron is director of Saclay; and Prof. M. Roubault is head of the uranium mining and prospecting work.

Perrin and his associates recognize that the French nuclear research development will continue to be strictly limited by lack of funds, but they expect that France's purely national program will be supplemented within a few years by the cooperative program of the European Council for Nuclear Research of which France is a member.

Germany . . .

Political obstacles stand in the way of nuclear development work in Germany, but much thinking and planning is going on in anticipation of the time when bans on such work are lifted

FRANKFURT—The statement that "Germany has stood still since about 1944 as far as atomic-energy developments and research are concerned" can perhaps be taken as the core of any realistic review of today's atomic-energy work in this country.

Conflicting policies handed down "from above" during Hitler's regime, lack of clear-cut direction in a research and development program, and finally Allied bombing of existing research centers and production facilities slowed down and finally brought Germany's atomic-energy program to a complete standstill.

Since the end of the war, a ban on atomic-energy work has been in force. This ban will continue in force until the contractual agreements and the EDC (European Defense Community) treaty are ratified by the nations concerned, including Germany.

An Allies Representative Speaks

"After these diplomatic and political hurdles have been cleared," Clarence A. Wendel, special assistant to the director, Office of Political Affairs, U. S. High Commission for Germany (HICOG), at Bonn, says, "Germany will be able to build a moderate-sized reactor which will enable the nation to conduct experiments and produce radioisotopes, although not as wide a range of the latter as is produced in the United States.

"The Germans have received some isotopes from Harwell; when the time comes, they'll be able to produce these, and other isotopes not available from Harwell. It will be an expensive operation, but it has almost become a matter of national prestige for them to be able to conduct their own research and experimental work. Germany will most probably set up its own atomic energy commission on a federal level, supported by federal funds; possibly, industry may make a financial contribution.

"Germany will not be allowed to produce or even to have the capacity to produce a sizeable amount of fissionable material, under the terms of the contractual agreements. However, these terms come up for review within two years. As matters stand now, Germany will be limited to the production of 30 tons of unseparated uranium the first year, after that to 9 tons yearly. But it is not so much the limitation on materials to be produced, as it is the limitation on establishing large facilities that will determine future developments."

Wendel added, "Indications now seem to point to the eventual construction of a graphite-moderated reactor. This appears rather surprising in view of the past German tendencies to work with heavy water.

WERNER HEISENBERG: Considered man most likely to direct German nuclear research

"I don't believe that the Germans are ready to come up with any particularly startling developments in the near future, nor do they desire to do so. National prestige and the hope of training a core of young scientists who can apply the principles of atomic energy in, say, ten years are now the primary reasons for them to get back into the atomic-energy field.

"After the Allies declassify and release information on power reactors, the Germans will probably be able to contribute a great deal in the fields of metallurgy and heat transfer. Thus far, they have concentrated on applications of atomic energy in agriculture, medicine and chemistry."

A German Physicist Speaks

Prof. Werner Heisenberg, director of the Max Planck Institute for Physics, Göttingen, was also interviewed by NUCLEONICS for his views on German progress. Prof. Heisenberg is considered Germany's top expert in the field of atomic energy and, according to HICOG's Wendel, will probably head Germany's future atomic energy commission.

Heisenberg's comments on the following page can perhaps be taken as representative of the general feelings of

the men working in the field in Germany today.

On work of past decade. "The most significant technical development in Germany within the past decade, I feel, was the determination that a reactor could be constructed with about 2 to 3 tons of uranium and 2 to 3 tons of heavy water, and that we could produce atomic energy for work in chemistry and medicine. You must remember that the term 'within the past decade' brings us back to 1942. After 1943, German industry was no longer able to contribute significantly. Allied bombing stopped work in a number of significant spots and early in 1945 everything was 'over.' Since that time, a complete ban has been in effect. Thus, when we review the past decade of German work in atomic energy, we are really concerned only with the last couple of years of the war."

On work of next decade. "Again, here it will be a question of what we will be allowed to do and what we will be able to do. If permitted, our emphasis will probably be on building a uranium reactor to produce radioisotopes for use in medicine, chemistry, biology, and industry. We would like to produce ourselves what we now have to import from abroad and what is now merely being checked at the various Max Planck institutes. We still have to do a lot of catching-up; until we have done that we cannot foretell accurately what direction our work will take in the next ten years."

On technical significance. "Our attitude toward the technical significance of atomic energy is centered in the hope that we will succeed in the peaceful application of radioactive substances in the fields already mentioned. Aside from that, we are, of course, interested in doing all we can for the security of our population in case of possible atomic attack. But, excepting this one point, we are not interested in the military aspect of atomic energy."

On reactors. "We will have research reactors and reactors to produce radioactive substances within the framework of the contractual agreements. These reactors may be limited to 1,000 kw. The construction of power-producing reactors will not be possible due to the narrow limits imposed by contractual agreements."

On agencies and research centers. "We have no agencies for atomic energy work in Germany today. This has not been permitted thus far. After the contractual agreements are ratified, we will undoubtedly establish something like the United States' Atomic Energy Commission. It will be established by the government and will be a complete government agency. It is entirely possible that industry will give financial and other support to such an agency.

"There are no government centers for atomic-energy work at present. Neither are there any private centers for true energy work. All our centers are for research only. Most prominent of these are: Göttingen University (betatron research); the Institutes of Atom Physics at the Universities of Hamburg and Freiburg; the Max Planck Institute for Chemistry at Mainz; and the Max Planck Institute for Physics at Göttingen."

Key People

In addition to Heisenberg, among the men who will continue to play an important role in atomic-energy development in Germany is, first of all, Prof. Otto Hahn. (Hahn, "grand old man" of German research in the field, now devotes most of his energies and time to the presidency of the Max Planck Society.) Others are Profs. Karl Wirtz (Göttingen), Walter Bothe and O. Haxel (Heidelberg), W. Gentner (Freiburg), R. Fleischmann (Hamburg), and A. Flammersfeld (Mainz).

Because of the loose organization existing in Germany today, it is difficult to say exactly how many people are actively at work in the atomic-energy field, but the average estimate is less than 100.

LOI No 22

CONTRÔLE DES PRODUITS, INSTALLATIONS ET ÉQUIPEMENTS AYANT TRAIT À L'ÉNERGIE ATOMIQUE

LAW No. 22

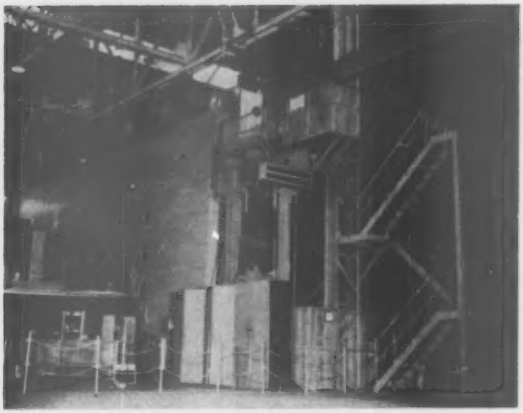
CONTROL OF MATERIALS, FACILITIES AND EQUIPMENT RELATING TO ATOMIC ENERGY

GESETZ Nr. 22

ÜBERWACHUNG VON STOFFEN, EINRICHTUNGEN UND AUSRÜSTUNGEN

OFFICIAL GAZETTE
OF THE ALLIED HIGH COMMISSION FOR GERMANY

RESTRICTIONS on German nuclear work forbid construction of reactors and high-energy accelerators



BEPO—Above-ground-level view of experimental face of Great Britain's largest reactor, which supplies heat for nearby buildings

SIR JOHN COCKCROFT: Directs research, is planning United Kingdom's nuclear-power program

Great Britain . . .

The first nation to use nuclear power to heat a building, England is at work on two breeder reactors. The British have shown themselves to be self-sufficient in atomic-development work and have a fully-rounded program under way

LONDON—The spectacular explosion of Britain's first atomic weapon in the Monte Bello Islands, Australia, on October 2 got the headlines. But a development of probably greater scientific importance is the report, now confirmed by Sir John Cockcroft, that Harwell is building a low-power breeder reactor and designing a high-power one. The low-power reactor, construction of which began in early summer, will be called, significantly, ZEPHYR—from the words "Zero Energy Pile."

It was with these developments in mind that Sir John made the following prediction: "The next five years should provide a considerable amount of experience in operating fast breeder reactors and developing the associated chemical processes. I believe the present decade will be devoted largely to the experimental and developmental phase of nuclear power in which we should operate some quite large-scale nuclear-power units. If we are successful, we should in the following decade begin to obtain some benefit from nuclear power."

In addition, it is known that design and feasibility studies have been proceeding on (1) a slow-neutron, enriched-uranium reactor, designed as a prototype power unit for special applications such as ship propulsion, and (2) a slow-neutron, natural-uranium reactor, designed to develop power for electricity.

The Harwell reactor BEPO is being used to heat Harwell offices and Harwell water. Cooled air is passed over the heat exchangers to produce a supply of hot water. This has been a very simple engineering problem. So far, three blocks of offices, containing about 250 rooms, have been heated this way. Some 2,000 tons of coal a year will be saved. No complications of any kind have been experienced in the operation.

Information Exchange

While the breeder-reactor program is undoubtedly the most important work now going on in Britain, the atomic explosion at Monte Bello is expected to yield valuable information on other technical aspects of atomic-energy development.

The real importance of the Monte Bello experiment is likely to be political rather than scientific. It may affect the U. S. government's McMahon Act, which in 1946 abruptly brought to an end all Anglo-American collaboration on classified nuclear research. The British believe that, with their own atomic weapon now proved, they have increased the chances of resuming collaboration.

Few Britons quarrel with the political motive behind the McMahon Act. A growing number, in fact, now regard it as not without compensation. In the last analysis, it forced Britain to become self-sufficient in the atomic-energy business.

Work Centers

Atomic-energy establishments now operating in Britain (at least those made public) break down this way:

Research:

Harwell, Berks.—Atomic Energy Research Establishment (AERE)

Amersham, Bucks.—Radiochemical Center (allied with AERE)

Production:

Risley, Lancs.—Design and administrative center

Springfields, Lancs.—Uranium-ore processing center

Sellafield, Cumberland—Plutonium production center

Capenhurst, Cheshire—Uranium-235 extraction center

Weapons:

Several centers, none officially disclosed

The whole program is the responsibility of the Ministry of Supply (MoS) and has Lt. Gen. Frederick Morgan as its controller. The research centers are under the direction of Sir John Cockcroft, production under Sir Christopher Hinton of the MoS, and weapons work under Dr. W. G. Penny, who directed the Monte Bello tests.

Costs

All figures relating to the cost of atomic-energy work in Britain have been carefully hidden from the public in sums appropriated to MoS for *all* its research and development work (aircraft, guided missiles, etc.). For all these purposes, MoS has been alloted about $1.54-billion since 1945. It is doubtful whether more than a quarter of this has gone into atomic energy.

Fuel Production

Two comparatively large reactors are producing plutonium at Sellafield.

Of the U^{235}-separation plant at Capenhurst, nothing has yet been revealed other than that it has been under construction since November, 1949. Neither have details been given on the methods used at Springfields for processing uranium ores. Intensive work is in progress at Harwell, though, to develop economic methods of extracting uranium from low-grade ore.

Industrial Participation

Outside of the Ministry of Supply complex, little atomic-energy work goes on in Britain. Contracts for certain nonsecret work have been placed with universities. Equipment contracts have been placed with private industry, but only two development contracts—with two of the larger electrical engineering firms—for design studies on reactors.

No British company has yet taken the initiative in seeking to develop power reactors.

Last summer, a parliamentary committee inquiring into the MoS's attitude on private industry coming into the atomic-energy business was told by Lt. Gen. Morgan, MoS controller of atomic energy: "We are beginning to consider the method by which we can incorporate the energies of industry into this whole project."

And Sir John, testifying before the same committee, said: "We have periodic conferences with representatives of industry on the question of atomic power on the average once a year . . . If they felt that they wanted to get into the business, they would tell us. But they say that at present they are so busy with rearmament work that they would rather wait."

The AERE

Harwell is responsible for initial research and development work for reactor construction, chemical plants, and such special materials as plutonium, graphite, heavy water, thorium, beryllium, and zirconium. All this work is taken as far as the pilot-plant stage.

It is completely responsible for production and distribution of radioactive and stable isotopes, working partly through the Radiochemical Center at Amersham. Last year 3,053 consignments of isotopes from Harwell were sold abroad to 37 different countries.

Harwell is further responsible for the initial research and development for the United Kingdom nuclear-power program.

Reactors. Besides the reactors under construction or in the design stage, Harwell has two graphite-uranium reactors: GLEEP (from the words "Graphite Low Energy Experimental Pile"), which started in 1947 and is now in use 24 hours a day for research purposes; and BEPO (from "British Experimental Pile O"), started up in 1948, which is used both for research and isotope-production. A recent improvement in the uranium cartidges used in BEPO has resulted in an increase in power output over its original design figure of 6,000 kw.

Accelerators. Besides three small accelerators, Harwell has a 110-inch, 180-Mev synchrocyclotron and a 30-Mev synchrotron.

"At present," says Sir John, "we do not have sufficiently energetic protons to produce mesons in appreciable numbers at Harwell. We have helped the University of Glasgow to build a large electron synchrotron (300 Mev) to produce mesons and we are designing a proton linear accelerator to allow us to do this kind of exacting work."

Waste Problems

So far, there has been little difficulty in dealing with radioactive waste, whether this be gaseous, liquid, or solid.

Somewhat elaborate precautions are taken in the case of disposal of liquid-waste products—in the Thames River at Harwell and in the sea at Sellafield. Long-lived and active materials which can be reduced in volume by concentration, are eventually dumped into the sea at selected points in the English Channel and the Irish Sea.

Personnel

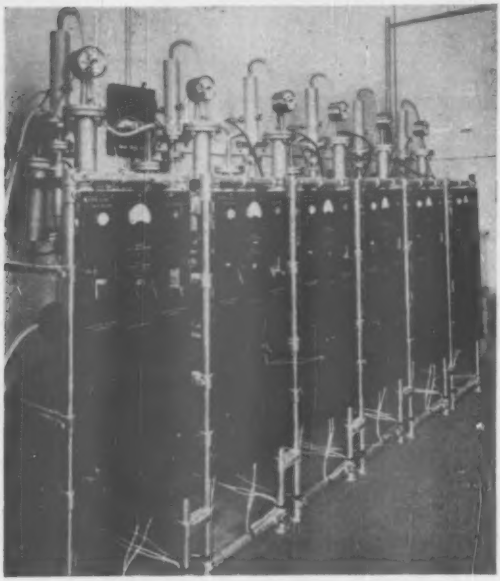
All scientists and engineers engaged in nuclear work—the exact number has never been disclosed—are civil servants. The problem of training and attracting technical personnel to Britain's atomic-energy establishments is coming in for a lot of thought at MoS. At Harwell the number employed has increased 80% in four years.

While low by U. S. standards, the upper limits of nuclear researchers' salaries are not far off those offered by British industry. MoS admits, however, that it loses some young recruits because starting salaries are, on the whole, less than those offered by industry.

Both at Harwell and the other establishments, appointees are given every opportunity and encouragement for further study, both under their immediate superiors, and at universities.

Italy . . .

Backed by a few industrialists, Italy's physicists are making plans to build a low-power reactor, but they need, almost more than money, the interest of the Italian citizenry



HEAVY WATER is produced in this electrolytic pilot plant at rate of 10 liters per year. Purity is better than 99.5%. Equipment belongs to CISE, industry-supported nuclear information center in Milan

ROME—After a decade of slow, interrupted, but sure progress, Italy in 1952 seems to possess the fundamental scientific and technical prerequisites for the construction of an experimental nuclear reactor. Barring the withdrawal of anticipated grants, it is possible that a low-power reactor can be started and completed within four years.

Italy had made a far-from-negligible contribution to nucleonics in the years immediately preceding World War II; however, the war itself did not stimulate specific achievements in applied nuclear physics in Italy as it did in other countries. The first three or four years of the past decade were waste years as far as atomic-energy research was concerned. The invasion of Italy, followed by the serious task of national recovery, posed more important problems to the Italian people during those years.

About the only step to strengthen her position through that period was made in 1945 in the form of financial aid to the Center of Nuclear Research in Rome. At that time, the National Research Council assigned the center an annual grant of 5-million lire (then equivalent to about $15,000). The center has since become part of the National Institute of Nuclear Physics.

At the present time, three groups are responsible for nuclear research in Italy. Besides the National Institute of Nuclear Physics, there is an industry-supported Information, Study, and Experimental Center (CISE), established in 1946, and a National Committee for Nuclear Research, created under a ministerial decree in July, 1952.

National Institute of Nuclear Physics. Currently receiving an annual grant of $300,000, the Institute has four sections: one in Rome, one in Milan, one in Padua, and one in Turin. The directors are Edoardo Amaldi, Piero Galdirola, Antonio Rostagni, and Gleb Wataghin, respectively.

The work of the Institute is devoted exclusively to fundamental research. It does not touch on problems of applied nuclear physics such as reactor technology and isotope separation.

CISE. So that Italy should not be entirely inactive in this field in which other governments have spent large sums, private enterprise has come forward where government aid has been lacking. To realize the full significance of this fact, which shows that some of the leading Italian industries have not been indifferent to the possibilities of applied nuclear physics, we must realize that scientific research in Italy is not as ardently encouraged as it is in other Western countries, such as Great Britain and the United States. Industrialists are all too inclined to look upon research grants as unproductive expenditure, to be

made as acts of patronage of the sciences but not with the conviction that they are serving their own interests.

Thus in 1946 when Prof. Giuseppe Bolla went to Eng. Vittorio De Biasi, general manager of the Edison Company, which controls about a fourth of Italy's electric-power output, and found him responsive to financing nuclear research, he felt a miracle had happened. The Edison executive saw, aside from the social duty devolving on industrialists, the possibility of opening up new sources of power for industry. Money was promised, and soon other industrial groups followed Edison's example—Cogne, Fiat, Sade, Montecatini, Pirelli, Falck, Terni. Recently the City of Milan joined them.

The outcome was the formation on November 19, 1946, of a company called the Centro Italiano Studi Esperienze (CISE)—an information, study, and experimental center financed by industrial grants.

Organized as a company, CISE has a board of directors on which sit the representatives of the founding companies, a physicist, and the president of Italy's National Research Council. The chairman of the board is Edison's De Biasi. A scientific committee, appointed by the board, composed of physicists, chemists, and representatives of the founding companies, superintends CISE work which is directed by Bolla, professor of experimental physics, and carried out at the Polytechnic School of Milan. Serving Bolla in an advisory capacity is a board, which includes, among other professors, Edoardo Amaldi, Bruno Ferretti, Carlo Salvetti, Enrico Persico, Piero Caldirola, Lamberto Malatesta, and Aldo Perus.

The industrial and university grants to CISE in 1947, the first year of its operation, amounted to $50,000; in 1952, they totaled $110,000.

With such financial means the company obviously has far from the amount needed to build a nuclear reactor; for such a purpose, it would need at least ten times the present grants. At present its purpose is a more modest one. It seeks to provide for studies, laboratories, and experimental installations, but above all, it wants to train research workers who will be able, when the time comes, to construct and operate a uranium and heavy-water experimental reactor of low power, with all the special equipment and laboratories that accompany such an installation.

Today CISE has about 35 research workers and 20 technicians and administrative personnel. Of these 55 people, 13 are engaged in general services (administration, drafting, maintenance, library, etc.), 2 in theoretical physics, 15 in experimental physics, 2 in reactor-project service, 6 in electronics work, 8 in heavy-water production, 5 in the chemical and chemico-physical laboratories, 3 in the uranium metallurgy laboratory, and 3 in the medical-biological laboratory.

CISE counts among its more important equipment and achievements:

1. A 400-kv proton and deuteron Cockcroft-Walton accelerator with pulsed and continuous ion source.
2. An 80-channel time-of-flight neutron spectrometer.
3. A 99-channel pulse-amplitude analyzer.
4. A pilot plant for production of heavy water (10 liters per year) at a purity exceeding 99.5%.
5. A pilot plant for uranium extraction from enriched metals.
6. A pilot plant for production of metallic uranium.
7. Modern electronic equipment, Geiger and scintillation counters, discriminators, synchroscopes, etc.
8. Plans for a low-power, uranium and heavy water nuclear reactor to be built in Milan.

Through arrangements initiated by CISE, the Polytechnic School of Milan is now offering a postgraduate course in applied nuclear physics. The course covers atomic physics; quantum mechanics; nuclear physics; reactor theory; techniques and measurements with ionisation chambers, Geiger counters, accelerators, mass spectographs, etc; electronics in nuclear physics; isotope separation, with special reference to heavy water; the chemistry and metallurgy of uranium; the geology of uranium; radiation chemistry; medico-biological applications; and problems of defense against atomic weapons.

The problems facing it are very difficult ones, but CISE stands as an example of what can be done with trifling financial means rather than as a finished achievement.

National Committee for Nuclear Research. The pressure of internal political problems of immediate urgency having declined in recent months, the Italian government has been more disposed to consider such matters as scientific research. In July, 1952, under a ministerial decree of July 1952, it appointed a National Committee for Nuclear Research, presided over by Prof. Francesco Giordani.

The tasks of this committee are in some ways wider than those assigned to similar atomic-energy committees of other nations as it is also charged with laying the plans for fundamental research work in nuclear physics.

The committee is financed by contributions from the Ministry of Industry, the National Research Council, and other bodies. The amount appropriated for its use has not yet been definitely fixed, but it will be around $1,500,000. This includes the grants to the National Institute of Nuclear Physics mentioned earlier and to the European Council laboratory. It is not much, but such an annual grant will make it possible to undertake and complete, within four years, the construction of a low-power nuclear reactor.

In carrying out its work and achieving the tasks entrusted to it, the committee will rely on the one hand on the National Institute for fundamental research work, on the other on CISE for work relating to applied nuclear physics. The forms this collaboration will take have not yet been defined, but they will surely be devised on reasonable lines.

Popular Support Needed

If we take as our base the work accomplished in the last ten years, it "is difficult," Prof. Bolla states, "to foresee the probabilities for the next decade. The first goal is an experimental reactor; it would then be desirable to construct a much more powerful reactor."

For the present, however, these are only wishes, as the general attitude of the country in relation to the technical importance of atomic energy is one of indifference. In the opinion of the man in the street (and not of him only), atomic energy is something with which others are concerned: the Americans, the English, etc. Such matters are never discussed, for instance, in Parliament. The future development in the field of atomic energy will therefore largely depend on a marked change in this general attitude.

The Netherlands . . .

The Dutch have started a nuclear-power feasibility study. Results will eventually be shared with Norway, Netherlands' partner in the Kjeller reactor project. With pile-produced isotopes of their own, the Dutch can now expand their nuclear studies

C. J. BAKKER

AMSTERDAM—It was Dutch foresight in buying Czechoslovakian uranium before World War II that made possible the Dutch-Norwegian collaboration in nuclear research after the war. Like Norway, The Netherlands shares the opinion that its joint reactor and research establishment is the country's most worthwhile technical accomplishment in the past ten years. (*Editor's Note:* The main details of the operation of the Joint Establishment for Nuclear Energy Research, run cooperatively in Kjeller, Norway, by the Dutch and Norwegians, are given in the article on Norway on p. 21. The description here serves to clarify certain aspects of the partnership from the Dutch point of view.)

Key man in Dutch nuclear research, Prof. C. J. Bakker, told NUCLEONICS his country's decision to take part in post-war nuclear development work was based on the realization "that atomic energy could be an invaluable power source—an extremely important fact for a country with limited coal and oil resources."

Bakker praised the "remarkable foresight" that led Prof. W. J. de Haas, of Leyden, to convince The Netherlands' government in 1939 to buy uranium oxide for a nuclear chain-reaction system. It was the possession of that material, purchased in Czechoslovakia and stored in hiding during the war, Bakker explained, that actually gave The Netherlands the opportunity to start its collaboration with Norway.

Today a team of about ten Dutch scientists is at Kjeller doing research and other technical work connected with the 300-kw reactor, for which The Netherlands supplied the uranium. They are also engaged there in research on a proposed 10,000-kw reactor, presumably a heavy-water-type experimental unit for ship propulsion, and on other power and reactor-materials problems.

A neutron velocity spectrometer, developed at Utrecht under the guidance of Prof. J. M. W. Milatz, is now in operation at the establishment in Norway. Neutron-diffraction research is getting special attention from the Dutch working at Kjeller.

Amsterdam Center

The principal laboratory for atomic-energy development work is the Instituut voor Kernphysisch Onderzoek (Institute for Nuclear Research), established in 1946 at the University at Amsterdam. Bakker, director of Amsterdam's Zeeman Laboratory, is managing director of the Institute. A synchrocyclotron, built there under his guidance, is a source of 30-Mev deuterons and 60-Mev alpha particles. Until isotopes from the Kjeller reactor were first made available to The Netherlands recently, Dutch scientists had to rely principally on this accelerator and on sources abroad for their radioisotopes.

Reactor Committee

To supervise all work on research with reactors and their technical development, a Netherlands reactor committee has been organized, with Bakker as chairman. Its membership includes Profs. J. Clay, J. M. W. Milatz, J. H. de Boer, C. J. Gorter, and W. J. Beekman, secretary.

Power Studies

Bakker, who divides his time between the Zeeman Laboratory, the Institute for Nuclear Research, the Kjeller establishment, and the European Council for Nuclear Research on which he serves as a study-group chairman, made the following statement to NUCLEONICS:

"There is a growing feeling in The Netherlands that in the next decade considerable effort will have to be made in the technical development of atomic energy. As the power consumption in the country is steadily increasing, new power stations have to be built and the question arises whether one can already contemplate building nuclear power stations; this question is a very important one and has to be answered definitely as soon as possible.

"This explains the deep interest the KEMA (Company for the Testing of Electrotechnical Materials) at Arnhem shows in this development. KEMA (under the management of Prof. J. C. van Staveren) is a research laboratory set up by the joint power stations in The Netherlands. An agreement has recently been reached by the Organization for Fundamental Research on Matter and KEMA, by which a combined research group will work in the KEMA laboratories. All research for reactor development, which can be carried out without having a reactor available, will be undertaken. Close cooperation with the reactor group at Kjeller is foreseen.

"The economical aspects of atomic energy are being studied by a combined group representing the Organization for Fundamental Research on Matter and the Organization for Technical Physical Research."

Future Cooperation?

The Dutch expect great things from the Norwegian-Dutch cooperation. A country as small as theirs, they say, with neither the funds, manpower, nor raw materials for operating large nuclear establishments of their own, must continue to lend their support to cooperative ventures like the Kjeller and European projects.

CONFERENCE at control panel of JEEP, Norwegian-Dutch reactor, centers around Gunnar Randers, director of Kjeller project. Odd Dahl (right), in charge of the reactor's construction, and K. P. Lien (center), project electronics engineer, look on

Norway . . .

With Netherlands' uranium and Norwegian heavy water and ingenuity, Norway, at a time when university research was at low ebb, built a reactor. It is now working on nuclear ship-propulsion problems

KJELLER—European nations in the midst of deciding on aspects of large-scale cooperation in nuclear research can look as an example to Norway, base of the first peacetime international venture into reactor research. The building and successful operation of a reactor with the Dutch stands out, without doubt, as the most significant technical accomplishment in Norwegian nuclear research in the past decade. In this regard, it is difficult to overlook the part Norway continued to play during this time to supply the world with heavy water.

Story of Heavy Water

Norway's atomic age started slightly prematurely in 1934 when Leif Tronstad, a professor of chemistry at the Norwegian Institute of Technology in Trondheim, persuaded the industrial firm Norsk Hydro to start large-scale production of heavy water. He did this, not because he anticipated its use as a pile moderator, but because he recognized its usefulness in experimental nuclear physics.

Since that time, the Norsk Hydro plant has supplied practically all nuclear laboratories in the world with heavy water. Ten years later, Tronstad was killed on a secret mission from England to Norway to prevent the Germans from exploiting this same heavy-water plant.

Although the plant was partly destroyed during the final phase of World War II, it was running full speed again by 1946. "The continued emphasis on heavy-water production, together with the Smyth report," a Norwegian physicist told NUCLEONICS, "was enough to inspire anybody with the idea of trying to build a nuclear reactor in Norway." There were other factors, however, that made such a project seem tempting.

During the war, the universities had been closed; as a consequence, the scientific spirit of the country was low. To start educating a new generation of physicists and engineers was a long-term project. Also, there seemed to

be little incentive for the younger generation to study nuclear physics as long as there were neither experimental facilities nor the prospects of getting some in the near future. Something had to be done.

The Kjeller Reactor

A young Norwegian astrophysicist, Gunnar Randers, who had spent the war in America and England, proposed that the best way to get the facilities, provide student incentive, and at the same time establish a center of nuclear research in Norway, was to build a heavy-water reactor.

The Norwegian Ministry of Defense offered 5-million kronor (at that time, about $1,000,000) toward the project, and the Norsk Hydro firm offered to contribute twice the government's appropriation. To allay civilian misunderstanding that this was a military undertaking, the project was shortly after taken out of the jurisdiction of the defense department and made a responsibility of the newly created Norwegian Research Council. Construction was started at a site in Kjeller, near Oslo.

Dutch Offer Uranium

The task remaining was to get uranium for the reactor. Uranium mining was started in southern Norway, and an ore-processing plant was built and put into operation. By 1950, the pile, with its shielding, electronic equipment, tank, and heat-exchanger system, was ready but uranium production had not kept up. It looked as if Norway would have the first uraniumless reactor in the world.

This was the point at which The Netherlands joined Norway in its reactor project. The late Dutch scientist, H. A. Kramers, visiting Norway at that time recalled that his colleague, Prof. W. J. de Haas, had several tons of uranium which had been purchased before the war. It was acquired for the Norwegian reactor with the understanding that the project would become a joint Dutch-Norwegian venture. A year later, in 1951, the reactor was put in operation. A full account of the reactor and its components was published in November, 1951, in NUCLEONICS in an article by Gunnar Randers and Odd Dahl.

Dahl, now head of the department of applied physics of the Chr. Michelsen Institute in Bergen, Norway, was responsible for most of the construction details. He had earlier worked on the design and construction of Van de Graaff generators in Norway and in Washington, D. C. The Kjeller pile, originally planned for 100-kw output, now operates at 300 kw. It has a flux of 10^{13} n/cm²/sec.

Joint Direction

The reactor, together with radioactivity and physics laboratories, all at Kjeller, comprise what is now called the Joint Establishment for Nuclear Energy Research, which Randers heads as director. The total cost of the reactor, without the uranium, and the associated laboratories was $2,360,000.

Work at the establishment is directed by a six-man Norwegian-Dutch Atomic Energy Board, the chairmanship of which is rotated. Prof. J. M. W. Milatz of Utrecht is the present chairman. The other Dutch member is Prof. C. J. Bakker of Amsterdam. The third Dutch appointment, at present vacant, was held by the man responsible for getting the uranium for the project, Prof. Kramers of Leyden, who died recently. The Norwegian members are Prof. Björn Trumpy and Eng. Odd Dahl of Bergen and Director N. Stephansen of Oslo.

This group, with Randers, formulates policies for all Norwegian-Dutch atomic-energy development work. "The establishment is actually run as an open research institute," according to Randers. In addition to the Norwegian-Dutch members, he explained, the staff includes a number of scientists from other nations—Switzerland, Sweden, Italy, Yugoslavia, and the United States.

Support of the establishment by government and industry is increasing rapidly. Randers noted that industry, in particular, has shown a very active interest in the work.

The problems of organization, as with any joint undertaking, for a time seemed to delay actual scientific accomplishments at Kjeller. All operations, however, have since been coordinated reasonably well, and the Kjeller enthusiasts point to this as a good sign for other small countries of Europe that similar cooperation is both possible and workable.

Isotope Production

Until recently, radioisotope production in the Kjeller reactor was not emphasized to the exclusion of other operations. A procedure has been worked out for routine production, and the reactor is now being operated day and night so that regular distribution of isotopes for medical and industrial use can begin soon. The establishment has contracted with a Norwegian pharmaceutical firm, NYCO, and a Dutch firm, Philips-Roxane, to handle distribution.

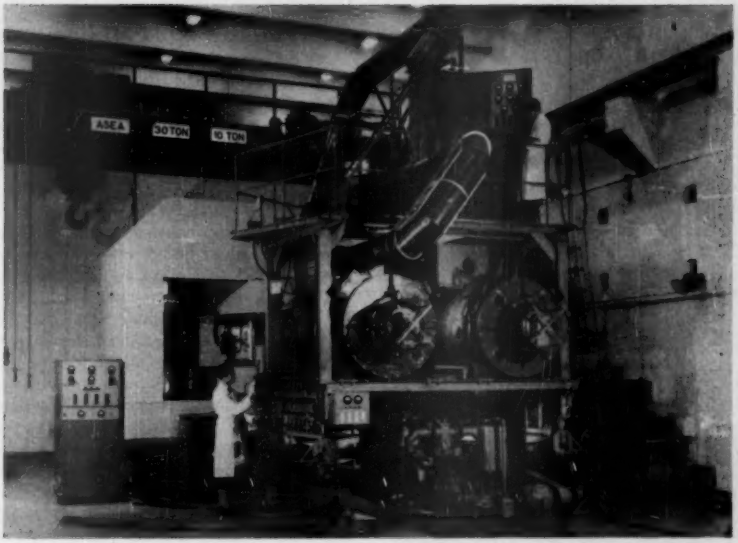
Attitudes on the Future

The Norwegian nation is generally becoming aware of the value of atomic energy as a force for more than just military use. Demonstrations of the practical uses of radioisotopes and nuclear power for additional electrification helped to bring this about. Previously, the people felt that their water power would keep them going as far in the future as they cared to think about, but even the Norwegians, with more kilowatts per head than any other nation in the world, were wont to admit that electricity was not available everywhere it was needed.

Of particular importance, the people feel, is the use of nuclear power for ship propulsion. The Norwegian merchant shipping fleet is completely dependent on import of fuel from abroad, a fuel that is rising in cost each year. The possibility, they say, of running part of their merchant fleet by atomic energy must at least be investigated so as not to lose out to foreign shipping.

The Norwegian shipowners and the Norwegian government favor the idea, put forth recently, of building a heavy-water reactor of about 10,000 kw as a preliminary experimental unit for ship propulsion. If nuclear-powered vessels are an imminent reality, they want to be able, they say, at least to discuss the problems intelligently.

The Norwegian pile-builders, thus, do not intend to rest on their laurels. With their Dutch associates, they are talking of building other and better reactors. In the meantime, they are satisfied with the present reactor as a research tool. All aspects of reactor technology—pile kinetics, shielding problems, cooling systems, radiation monitoring—are fast becoming familiar working fields for the small international staff at Kjeller.



WORLD'S LARGEST fixed-frequency cyclotron (88½-inch dia.) is at Nobel Institute of Physics

Sweden . . .

Nuclear-power development is being watched with special interest by the Swedish people who, in the meantime, are building a small research reactor, extracting uranium from shale, and showing their inventiveness with improved instrumentation

STOCKHOLM—Sweden is making important contributions in many areas of nuclear research. With no access to uranium in quantity, the Swedish are pioneering in new uranium-extraction methods and will have a 100-kw reactor completed by 1954.

Government-Industry Project

In organization, atomic-energy work follows the pattern of government-industry collaboration successfully practiced by Sweden in other fields. Thus, while the broad lines of development are laid down by the Swedish Atomic Energy Commission, a government body, the practical work is delegated to a special company, AB Atomenergi, in which 2 million kronor ($387,000) of the stock are held by the government and 1.5 million ($290,000) by fifteen private corporations. Among the private shareholders appear well-known names like Asea (electrical equipment), Boliden (mining), Stora Kopparberg (steel, pulp, chemicals), besides one of the big power companies.

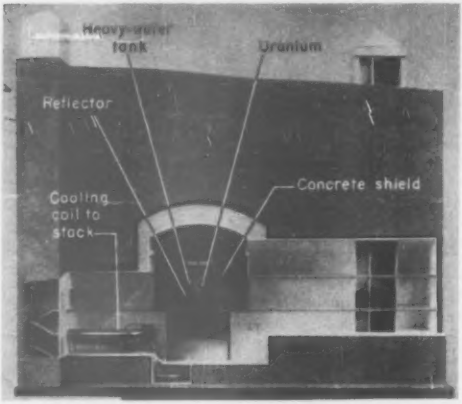
The business of AB Atomenergi is to produce uranium and moderator material and build reactors. The Atomic

HARRY BRYNIELSSON: Heads AB Atomenergi, management company for Sweden's nuclear development program

MANNE SIEGBAHN: Directs Nobel Institute of Physics, offering unique facilities for nuclear research

Energy Commission, on the other hand, is primarily concerned with the organization and support of research. There is close cooperation between the atomic energy company and the commission, and there are several members of the commission on the company's board of directors.

The feeling in Sweden is that for a small country, this setup is natural and advantageous. As Harry Brynielsson, managing director of Atomenergi, expresses it: "The government, obviously, is greatly interested in the technical applications of atomic energy—and the large financial outlay involved makes government participation necessary in this field. The operating expenses of Atomenergi, for instance, are wholly met by government allocations. This does not mean, though, that industry is a mere sleeping partner in the business. Not only the companies holding



SWEDEN'S first reactor, being built in Stockholm, will have elevators and stairs to underground rock chamber where reactor and laboratories are housed. Model shows arrangement for dissipating reactor heat to 130-foot stack

stock in Atomenergi but others, too, contribute to the work in many ways."

So far Atomenergi has invested about $675,000 in plant, and spent some $3,850,000 on research. There are about 250 persons directly engaged in the work (of these, 140 are employed by AB Atomenergi).

Uranium from Shale

The most significant technical development in Sweden, it is agreed by all engaged in atomic energy work, has been the solution to the problem of extracting uranium from shale. A number of research workers have contributed to this achievement, though the work was carried on chiefly in Atomenergi's chemistry laboratory under Erik Svenke.

Sweden's shale deposits are large, even from an international viewpoint. The only deposit at present being worked is that at Kvarntorp, where the shale is mined by a government-owned oil company. Smaller deposits are known to exist, however, and prospecting is going on continuously. The difficulty is that the uranium content of the shale hardly exceeds 200 grams per metric ton. Embedded in the shale, though, are small lumps of kolm, a hydrocarbon containing up to 3,000 grams of uranium per ton. During the past year, Atomenergi has been separating the kolm from the shale by the sink-and-float method in its concentration plant at Kvarntorp. But to produce uranium on any scale, the kolm and the shale will have to be treated simultaneously, and a plant for doing this by an entirely new method is now being erected. The technically pure product from Kvarntorp will be further processed at the Atomenergi plant in Stockholm.

Reactor Being Built

Training of personnel means training in reactor technology. Sweden's first reactor will be ready for operation by the end of 1953 or early 1954. It is a research type, fueled by 3–4 tons of uranium metal, and cooled by air. As moderator, heavy water from Norway will be used.

In one respect, this first Swedish reactor will be unique: it is being built underground in a chamber carved out of bedrock. Besides affording protection against aerial bombing, this arrangement allows the reactor to be located in Stockholm, immediately adjacent to the Academy of Engineering Science's research station—radiation being absorbed by the solid granite rock formation. Problems connected with this reactor are being worked out in Atomenergi's nuclear physics department under S. Eklund.

"This reactor will be used for isotope production and for pure scientific research," Brynielsson explains, "but its most important function is to give us experience in reactor technology."

Regarding the use of atomic energy for power production, Brynielsson points out that obviously Sweden cannot go directly from this small reactor to a real power reactor. "But we hope to start taking the steps in between by building a reactor up to 10–20,000 kw. In other words, the next ten years will bring us closer to the goal." This goal is especially important in a country with so little in the way of mineral, oil, or coal resources. It is estimated that Sweden's principal source of energy—water power—will be harnessed to the full within twenty years. This would mean that the country would then be completely dependent on imported fuels for any further expansion of power use—unless atomic energy comes to the rescue.

Extensive Use of Isotopes

The utilization of radioactive materials is high in Sweden compared with other West European countries. Sweden imports more isotopes from Brookhaven and Harwell than any other country.

Most of the imported isotopes are used for medical and biological research, but industrial applications are increasing sharply. Over thirty companies use them.

The Royal Institute of Technology in Stockholm, and Chalmers University of Technology in Gothenburg, act in an advisory capacity to industry. A private equipment manufacturer, LKB-Produkter, has recently entered the field, offering full services to industry.

Scientific Work

"It is sometimes said that Swedes are not especially interested in purely theoretical scientific work," says Gosta W. Funke, executive secretary of the Atomic Energy Commission, "and in a sense I suppose that is true. Without in any way detracting from the pure theory work that is being done in Sweden in the nuclear field, however,

one can say that the emphasis has been on the design and construction of finer apparatus and instruments, and on fundamental research in precision measurement."

This trend can be explained by several factors, the most obvious being a characteristic Swedish leaning toward mechanical inventiveness and skilled workmanship.

A hardly less important factor is that, with the coming of atomic energy it became clear that nuclear work would have to be carried on on a much larger scale than had been previously envisaged. The pace of scientific research will be accelerated as new equipment is completed.

New synchrocyclotron. A case in point is the frequency-modulated 200-Mev synchrocyclotron which is nearing completion at the Gustaf Werner Institute for Nuclear Chemistry at Uppsala. This institute is headed by the Nobel laureate, The Svedberg. The cyclotron, second largest in Europe, will be used especially for spallation reaction work.

Nuclear chemistry. The advancing reactor program will greatly expedite work in nuclear chemistry—for as K-E. Zimen, head of the nuclear chemistry department at Chalmers, points out: "So many of the problems involved in reactors are chemical problems that the nuclear chemists' job is relatively large in the atomic energy field." One of the most important separation problems currently being investigated at Chalmers is the separation of Np^{239} from neutron-irradiated uranium.

Natural radiation in humans. Among the research areas in which Sweden is making important contributions is the investigation of natural radiation from the human body and the construction of instruments for its measurement. This work is being carried on by Rolf M. Sievert at the Institute of Radiophysics, Karolinska Hospital, Stockholm.

Nobel Institute program. Here, under the direction of Manne Siegbahn, a Nobel prize winner, new principles for precision measurement are being worked out, especially in nuclear spectroscopy. This institute, too, offers a unique combination of facilities for nuclear-physics work not available at any one institute elsewhere.

What is thought to be the world's largest cyclotron of conventional fixed-frequency type has been in operation at Siegbahn's institute for about a year. It produces 25-Mev deuterons or 50-Mev alpha particles, and has a pole diameter of 88.5 inches. Constructed by H. Atterling and G. Lindström, it is currently being used for the production of radioisotopes.

"An interesting problem which will be tackled in the near future," says Atterling, "is the acceleration of heavy particles, such as nuclei of carbon and nitrogen, for the production of transuranium elements."

A small 7-Mev cyclotron is used for the production of radioactive materials and as a source of neutrons. The Institute also has a 1.5-Mev Cockcroft-Walton machine.

An electromagnetic isotope separator has been in continuous operation since 1949. S. Thulin built the instrument together with I. Bergström. The usefulness of this isotope separator has prompted plans for two smaller ones of the same type, one of which will be used especially for producing targets for Van de Graaff generators.

Spectrometers. The Nobel Institute's double-focusing spectrometer designed by Nils Svartholm and Kai Siegbahn measures relative energies of gamma radiation with a precision of 1 part in 10,000—the highest degree possible for the electron-focusing type of instrument—and has an instrument line width of 0.2%.

UNDERGROUND LABORATORY in Stockholm, shielded by 180 feet of granite, was built by Sievert's group to study natural radiation from humans. Low background, plus special equipment permit gamma measurements of < 0.001 μg (5% accuracy)

At the Royal Institute of Technology, Kai Siegbahn has constructed an interesting new type of instrument which consists of two beta spectrometers. They are magnetically screened so that they are independent of each other, and the angle between them can be varied. Equipped with very fast coincidence counters, these two spectrometers make an instrument for angular correlations of radioactive samples.

New type of accelerator. Construction of a new type of accelerator, based on a principle developed early in 1952 is being undertaken by Hannes Alfvén at the Royal Institute of Technology. It is anticipated that this machine will be less expensive and more efficient than existing types of the same energy.

There are two 4-Mev Van de Graaff generators nearing completion in Sweden, one at Chalmers and the other at Lund University.

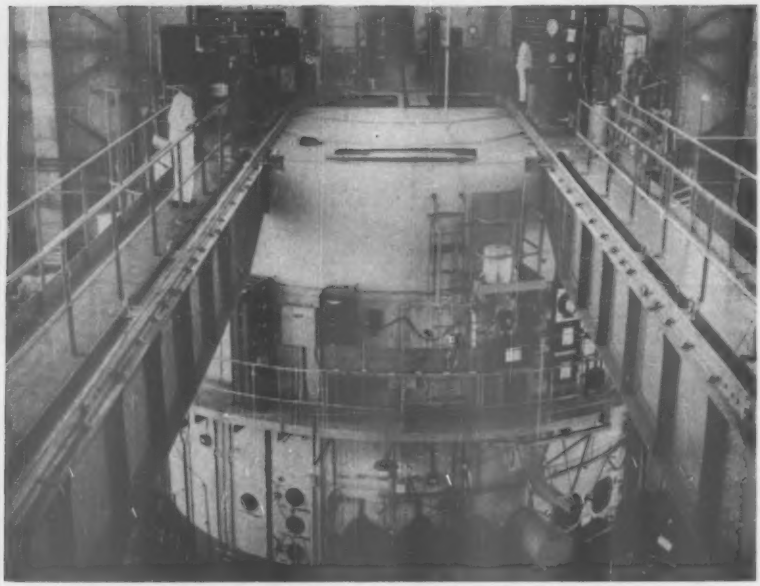
These machines, and others too numerous to mention, make it possible to assert that Sweden has the most completely equipped nuclear science laboratories in western Europe, next to England.

Interests of the Future

With present techniques, the construction and operation of very high-energy accelerators, 1 Bev or more, are projects in which nations with limited resources cannot compete because of the great cost and number of personnel involved. Thus Sweden looks upon the planned European nuclear laboratory as the way it and other small member countries can advance in such research.

Belief in the great significance of atomic energy for peaceful purposes in the future is implicit in the industrial, technical, and scientific work Sweden is doing in this field.

The main interest, of course, is in large-scale production of electric power. Next is interest in the nuclear propulsion of ships. Naturally, too, in view of the high costs entailed in the extraction of uranium from shale, Sweden is interested in developments in breeder-reactor technology.



CANADA'S most significant development in decade past is NRX, powerful heavy-water reactor

Canada . . .

Research in Canada proceeds on the assumption that atomic energy will find important new industrial uses and pay for itself in the long run. The Canadians are pushing construction of another advance-design reactor and expanding their uranium-mining activities

OTTAWA—One of the high-priority jobs Canada plans to tackle in the next decade is to find a way to produce fissionable material more economically and then make profitable, industrial use of it. With its research geared entirely to the industrial and nonmilitary aspects of atomic-energy development, Canada seems likely to continue to be one of the best-equipped nations for this task.

Possessor of one of the highest-flux reactors in the world, Canadian scientists are in the process of acquiring another, larger reactor for research and isotope and plutonium production. When this new reactor is in operation, the next step will be one or more power reactors.

The principal aspects of Canada's current contributions are: (1) the production of raw material, through exploration and development of uranium-bearing deposits in the northland in combination with research on ore-processing and handling methods; (2) the production, distribution, and research in the use of radioisotopes which are available in large quantities from its high-flux reactor; and (3) research into other applications of atomic energy.

The hub of much of Canada's work is the NRX reactor at Chalk River, Ontario, of which C. J. Mackenzie, president of the Atomic Energy Control Board and of Atomic Energy of Canada, Ltd., says: "The most significant Canadian atomic-energy development of the past decade has been the successful operation of Canada's second reactor, a natural-uranium, heavy-water reactor known as NRX.

"Designed and constructed by Canadian engineers, it was first brought into operation in the summer of 1947 and, until the end of 1951 at least, had the highest neutron flux of any reactor known."

Future Trends

During the next decade, it appears certain that scientific work in Canada will be directed toward seeking new uses for atomic energy and reducing the cost of its production. Emphasis will be put first on the construction of a larger and improved reactor for research and plutonium production and, after that, on construction of power reactors.

Mackenzie is certain that it is too early to predict the direction that future atomic-energy developments will take. Another fundamental discovery like the discovery of fission may bring about developments not even dreamed of today. Consequently, he has emphasized the importance of continuing all aspects of research and of having available well-trained groups ready to apply any new discoveries in this field.

The fact of fundamental importance as of today, as Mackenzie sees it, is that fissionable materials can be produced in practical quantities. "We should not think only in terms of conventional power as such," he says, "for surely the enormous heat-producing possibilities of fissile material will find many uses in chemical, metallurgical, and other processes. It seems to us that we have two broad problems: first, to make fissionable material economically and, then, to find profitable industrial uses for this product.

"As we see it, in the immediate future, the greatest need and scope for the well-proven strength of private initiative and competitive spirit lies more in the second field, of finding profitable uses for fissile material in existing and in as yet unthought-of industrial processes, rather than in the production of the primary product."

The NRU Reactor

A new and larger heavy-water reactor, Canada's third, is under construction at Chalk River. Known as NRU, it is due for completion in 1954 or 1955. It is intended, first, to enlarge the scope of scientific research and, second, to produce in larger quantities selected isotopes that are now in high demand (for example, cobalt-60). It will also make available in Canada more plutonium for export or for use in power reactors still to be built.

Studies on power reactors and their design are in progress. As soon as NRU is completed, the Canadians intend to start constructing the first unit of this kind in Canada. While no target date has been set, it is to be assumed that the power reactor might be in operation in eight or ten years.

Responsibility Split 3 Ways

There are three working groups that, combined, share the responsibility for atomic-energy development in Canada—one of these is a government agency, the other two are "crown" companies.

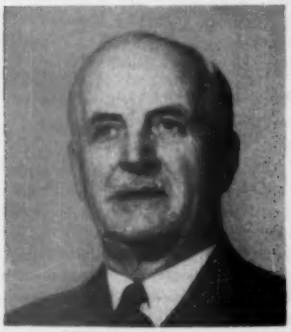
Atomic Energy Control Board. This is the principal Canadian agency for atomic energy work. Within limits set forth by the Atomic Energy Control Act of 1946, it makes policy and advises the government on policy decisions. It has power to regulate all production, processing, and dealing in products pertaining to atomic energy. Through ramifications extending both upwards and downwards, the board serves as a coordinating agency for departments of government and, to some extent, private industrial interests who are or may be interested in the progress of atomic research.

Upward, the board reports directly to a committee of the cabinet on scientific and industrial research. The committee is headed by Rt. Hon. C. D. Howe, minister of trade and commerce and also minister of defense production. Thus, at the political level, Howe is the key man in atomic energy, the minister who is responsible to parliament for the expenditure of funds voted for atomic research. The cabinet committee also includes the ministers of agriculture, fisheries, mines and technical surveys, national defense, health and welfare, and resources and development.

President of the Atomic Energy Control Board is Mackenzie, the key Canadian on the operative and administrative end of atomic-energy development. Other members of the board are: George C. Bateman, mining consultant from Montreal, Paul E. Gagnon, director of the department of chemistry of Laval University, Quebec; William J. Bennett, president and managing director of Eldorado Mining & Refining, Ltd.; and E. W. R. Steacie, president of the National Research Council of Canada.

Apart from its policy-making and advisory functions, the board's main job is the enforcement of controls. It decides who shall produce, use, and deal in atomic materials and under what conditions. Its legal powers are wide. It could also conduct research, buy and sell, and manufacture, but, for the most part it has used other agencies for these jobs and has remained a compact unit with a small staff.

Atomic Energy of Canada, Ltd. The principal operative agency in research is Atomic Energy of Canada, Ltd., a government-owned company created early this year



C. J. MACKENZIE: Presides over Atomic Energy of Canada, Ltd.

DAVID A. KEYS: Manages huge Chalk River establishment

W. B. LEWIS: Directs research and development at Chalk River

to take over the Chalk River research establishment from the National Research Council, which had operated it from its inception in World War II.

Mackenzie, during that period, was president of Canada's National Research Council but this year gave up that post to concentrate on atomic-energy developments as president of Atomic Energy of Canada, Ltd., and the Atomic Energy Control Board.

The nine directors of Atomic Energy of Canada, Ltd., include several executives of publicly and privately owned power agencies, selected with an eye to creating a liaison between the agency and potential users and distributors of atomic power.

Eldorado Mining and Refining, Ltd. This, the most important organization on the raw materials side, is another government-owned company which engages in the mining and processing of radioactive ores. Originally a private company, Eldorado was set up to produce radium from pitchblende deposits found on the east shore

ASSIMILATION of radiophosphorus by river organisms is checked by University of Toronto researcher, Frank Rigler

of Great Bear Lake. It was taken over by the government when the uranium content in its ores became a vital war material in the early stages of the atomic-bomb program. Eldorado operates its original mine at Port Radium on Great Bear Lake, and is presently spending several million dollars on the development of a new mine in the uranium-rich Lake Athabaska area of northern Saskatchewan. It has been designated as the sole agent for the purchase of uranium ores produced by private companies, a number of which are operating or planning to operate in the Lake Athabaska area.

The company's present refinery is at Port Hope, Ontario. Construction of a larger refinery is contemplated.

The company is financially self-sustaining. Although figures on uranium production are not available, it is generally assumed that Canada is a sizable producer, probably third among western producing countries, and Eldorado handles the entire Canadian output. Uranium produced in privately owned mines must be sold to Eldorado at prices fixed by the government. With the full exploitation of the Lake Athabaska ore bodies, Canada, pending exploitation of deposits known to exist in Australia and South Africa, could rank second to the Belgian Congo as a producer.

Work Centers

Ottawa, the national capital, as the headquarters of the Atomic Energy Control Board, Atomic Energy of Canada, Ltd., and Eldorado, ranks as one of the principal atomic-energy centers of Canada. Ottawa is also the site of the laboratories of the National Research Council, in which fundamental research is carried on.

The Department of Mines and Technical Surveys is actively concerned in the discovery and development of Canadian radioactive ore deposits. Its Geological Survey carries out geological investigations in areas where uranium has been or is likely to be found, and has compiled a special handbook giving technical advice to prospectors in their search for radioactive materials. Another section of the same department, the Mines Branch, operates ore-dressing laboratories and gives advice to uranium companies on the best method of recovering uranium from their ores. The Mines Branch operates ore-testing laboratories for analyses of ore samples sent in by prospectors and others.

Chalk River, 125 miles west of Ottawa on the south shore of the Ottawa River, is Canada's principal workshop on applied atomic-energy research and has no other activity. The plant includes the country's three reactors, two operating and one under construction, as well as extensive facilities for handling, packaging, and shipping isotopes produced in the reactors. To accommodate the employees, the government erected the village of Deep River, a self-contained community, complete with private houses, staff houses, shops, and schools.

Several universities are also carrying out atomic-energy research, some of it financed by the government. Their work is coordinated through the National Research Council. The projects include cyclotron research at McGill University, Montreal; cosmic-ray and isotope research at the University of Montreal; synchroton work at Queen's University, Kingston; mass spectrometry at McMaster University, Hamilton; betatron research at the University of Saskatchewan, Saskatoon; and particle-accelerator research at the University of British Columbia, Vancouver.

Working Staff

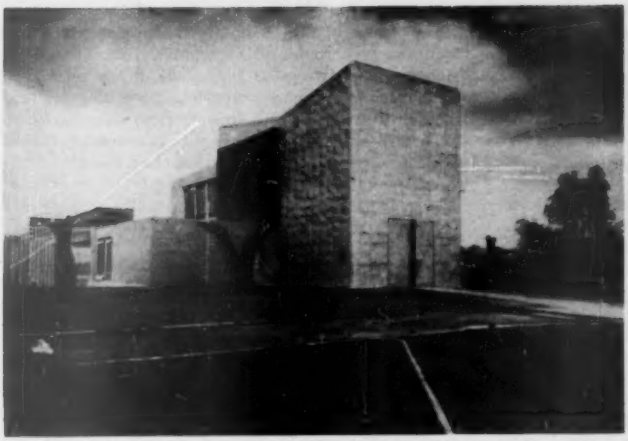
David A. Keys, a physicist, as chairman of the project coordinating committee is the senior resident officer at the Chalk River Establishment. W. B. Lewis is vice-president in charge of research and development.

Altogether more than 2,300 people are employed in Canada's atomic-energy program. Of these, about 1,500 are employed by Atomic Energy of Canada, Ltd., mostly at the Chalk River research establishment.

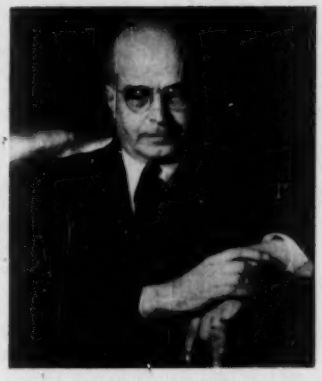
Cost of Program

The Canadian government's annual expenditure on atomic research runs between $18- and $20-million dollars. Total investment in the Chalk River establishment, including capital cost and operating expense, now stands at $60-million; it will be around $100 million by the time the new reactor is completed.

Howe regards expenditures on the atomic-energy program as neither a gamble nor a disinterested contribution to the advancement of scientific knowledge, but rather as a sound business proposition which will pay dividends on the capital invested and create new jobs and incomes for a larger number of Canadians.



NEW nuclear physics laboratory at University of Mexico houses new Van de Graaff accelerator and symbolizes Mexico's first steps in field



MANUEL SANDOVAL-VALLARTA: is spearheading Mexican nuclecr research

Mexico . . .

The Mexicans have started on a modest program of nuclear research, not primarily for its academic interest, but rather for the benefit it may ultimately bring to better the country's economy

MEXICO CITY—This fall, Mexico entered the nucleonics field when it opened a new nuclear physics laboratory containing a 2-Mev Van de Graaff accelerator. There is talk of building a small reactor, and the task of gathering the necessary material for it has been started. It is expected that uranium for the reactor will come from Mexican sources which, though as yet relatively unexplored, are thought to be rich in uranium-bearing ores.

Mexico's great hope is that the economic feasibility of nuclear power will be proved, and it is willing to help work toward this end. Its oil and coal reserves are not unlimited, and its people are rapidly outgrowing the country's agricultural productive capacity. Power reactors, therefore, could be the solution to a pressing dilemma.

New Center Built

The Van de Graaff unit, built by the High Voltage Corporation, Cambridge, Mass., is a positive-ion accelerator. Together with other facilities of the new laboratory, it is housed in a $25,000 building that is part of the science quadrangle of the new University of Mexico campus. The campus, located at the southern edge of Mexico City, has been built on a vast lava bed 2,000 years old.

Manuel Sandoval-Vallarta, head of Mexico's National Institute of Scientific Investigation, is one of the physicists responsible for creation of the laboratory at the university and for continued research in the nuclear field. Others include Carlos Graef Fernandes, director of the Institute of Physics of the university, and Fernando Alba, vice president of the Mexican Physical Society, who has been named director of the new nuclear physics laboratory.

Asked what was considered Mexico's most significant technical accomplishment in the atomic-energy field in the past decade, Sandoval-Vallarta pointed to "the development of a complete theory of homogeneous reactors, having as its principal aim the design and future construction of nuclear reactors, both for research and power production." "The theoretical results," he added, "were presented at the meeting of the Mexican Physical Society in Queretaro in April, 1952, and were further discussed in a symposium on modern research methods in physics in Rio de Janiero in July, 1952."

Power Reactor Their Aim

Sandoval-Vallarta, who has served with the Mexican delegation on the United Nations Atomic Energy Commission and lectured at the Institute for Advanced Study at Princeton University, indicated just one direction for Mexican nuclear research in the next decade: "Our only aim is the development of power reactors. We believe there is a great future, barely touched as yet, for the use of nuclear power." As for information on type, size, and

probable completion date of the planned reactor, the Mexican physicists responsible would not say.

Fernandez, speaking of the new Van de Graaff accelerator, says that, for the time being, at least, it is a "most adequate" machine for Mexico to begin investigations with and one that will facilitate the training of a body of young researchers who will be needed to operate other research units as they are added to the laboratory's facilities.

The first investigations with the accelerator will be on the properties of lithium. Later on, mutation research involving corn seeds will be undertaken. This latter research could be immediately profitable to Mexico, where arable land is limited and demands for better food supplies are increasing. Heavy hydrogen is being obtained from Norway to provide a deuteron source for the research.

Mexican Uranium

A major mining country rich in silver and copper, Mexico has never been carefully explored for commonplace minerals, let alone uranium. There have been scores of reports of uranium discoveries, however, and a few have been confirmed by reputable laboratories. If any sizable discovery has been made, it has never been made public. A rumor that Mexico was shipping uranium-rich earth to Russia from Oaxaca was repeated so frequently that it had to be denied by government officials.

In any case, Mexico has on its books a so-called "uranium law" to insure that all discoveries of uranium or other radioactive minerals automatically become the property of the nation.

Negotiations with U. S.

The United States has sent representatives to Mexico to negotiate for Mexican uranium—probably to help explore for uranium under an agreement to have first option on the purchase of any findings. These negotiations have been conducted in secrecy, and their outcome has not yet been revealed.

Argentina . . .

A legislative framework provides for an Argentine atomic energy commission and a national laboratory, but little is known of this country's technical accomplishments

IN 1950, Argentina, by decree of its president Juan D. Peron, created a national atomic energy commission. It was the first South American country to set up such a body. All those engaged in nuclear research in Argentina at the time were ordered to report to the commission.

Later decrees, in 1951, resulted in the creation of a National Board of Atomic Energy in the Ministry of Technical Affairs, charged with the direction and coordination of all work being carried out in connection with atomic energy. The commission, over which Peron is presiding officer, it was then clarified, was to serve only as an advisory organ to the government. These decrees further provided for the establishment of a plant to be known as the National Atomic Energy Plant of Bariloche, and for a national laboratory of atomic energy to function in connection with the plant.

The location of the plant is Argentina's isolated lake country on its western border. Properties transferred to the plant by the decrees include Huemul Island, site of the special government laboratory where Ronald Richter, the Austrian physicist, is carrying out experiments which last year resulted in his claiming new discoveries in the release of energy.

Informed sources reveal that a number of reputable Argentine physicists are proceeding with their own nuclear-energy studies in Buenos Aires entirely apart from Richter's questioned project.

Dutch Cooperation?

The visit of the Dutch nuclear physicist, Prof. C. J. Bakker, to Argentina last year was mistakenly attributed to a desire to have him observe the Richter achievements. Although he visited the Heumul laboratories, he has never publicly commented on them.

The principal reason for Bakker's visit, however, and one never made public, was that Holland was planning to sell nuclear equipment to Argentina. This plan may still go through, and it will more than likely be for the reputable Buenos Aires laboratories and not for the Richter establishment in Heumul.

Richter's project, in which he claimed to have developed a thermonuclear reaction, is practically entirely discounted by recognized Argentine physicists. They say that, if anything, he is using the Cockcroft process, first described in 1932, which uses protons on lithium targets, with the lithium converted into helium plus energy. Richter has said he is using an Argentine material, and Argentina is a producer of lithium.

Brazil . . .

The scattered interests of Brazilian physicists were brought together last year under a new agency that is now working enthusiastically to coordinate the country's nuclear research

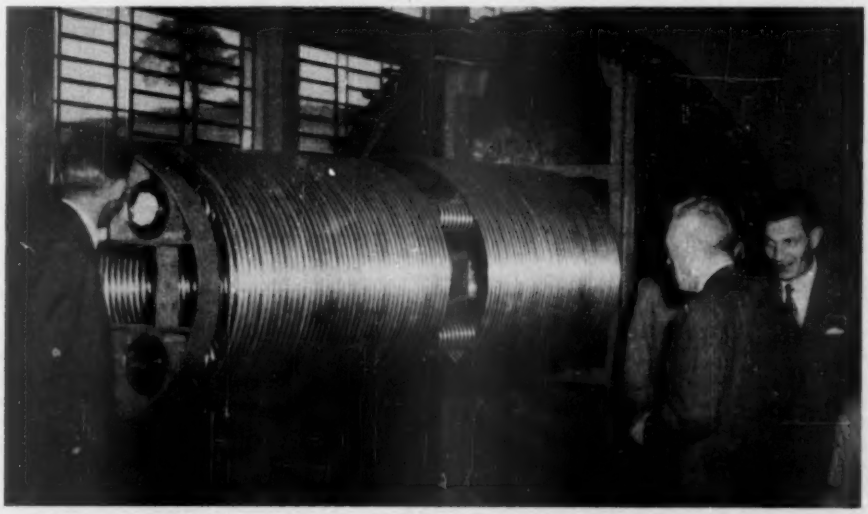
RIO DE JANEIRO—Plans for the next decade's work show that physical research and a raw-materials search are sharing the spotlight in Brazil's atomic-energy program.

Although as a nation it had reason to point with pride to the accomplishments of individual Brazilian researchers during the past decade, Brazil did not, until 1951, establish a government body to promote atomic-energy development. It is the creation of this body that seems to many to be Brazil's most significant development during the past ten years.

Named the National Research Council [Conselho Nacional de Pasquisas (CNPq)], the agency was established by law in January, 1951; in addition to the responsibility for promoting research in every branch of knowledge, it is charged with (a) the control of all activity related to atomic energy and the raw materials involved and (b) the task of stimulating nuclear research and the industrial use of atomic energy.

Some far-sighted men were behind this move by the government. One of these was Admiral Alvaro Alberto, who served as Brazil's representative on the United Nations Atomic Energy Commission, 1946–1948. He planned the Council, was appointed its first president, and today gives all his time and enthusiasm to its program for atomic-energy development.

Among the outstanding and original works influencing the establishment of CNPq, were those of a group of physicists who, inspired by the researches started in 1935 by one of their members, Gleb Wataghin, set up a center for investigations in nuclear physics and cosmic rays at the University of São Paulo. Their work received world-wide attention, as did that of the young Brazilian physicist, C. M. G. Lattes who, in 1947, participated in the discovery of the heavy meson and, in California in 1948, in its artificial production—events considered two of the past decade's most significant works in nuclear



NEW Van de Graaff generator at University of São Paulo is scheduled for completion by end of this year

ALVARO ALBERTO: Heads Brazil's National Research Council

C. M. G. LATTES: Directs work of Brazilian Center of Physical Research

J. COSTA RIBEIRO: Is scientific director of National Research Council

physics. When Lattes returned to Brazil, he organized the Brazilian Center of Physical Research, in Rio. Two important centers of research had thus been established before any government cooperation in atomic-energy development was formally available.

The other important consideration behind setting up CNPq was the fact that Brazil is perhaps the only country in the world that has large deposits of both thorium- (in the monazite sands of the coast) and uranium-bearing ores (in the mineral deposits of the state of Minas Gerais).

The annual budget of the National Research Council for 1951 was 30-million cruzeiros ($1,200,000); in 1952 it is 50-million ($2,000,000), and next year it will probably be 100-million ($4,000,000).

Serving as vice president under Council president Alberto is Col. A. Dubois Ferreira. Prof. J. Costa Ribeiro is CNPq's scientific director.

Attitude on Power

According to Ribeiro, the development of nuclear power for industry "would present a greater benefit to Brazil than it would to other countries with richer natural energy sources." To elaborate, he points to the fact that Brazil is relatively poor in coal and oil resources and that its largest potential sources of hydroelectric power are, in general, too far away from its scattered industrial centers to be of significant benefit.

Program Emphasis

In its program for the next decade, the National Research Council is objectively considering putting emphasis on the following steps:

1. The training of scientific and technical personnel in nucleonics, electronics, nuclear engineering, the chemistry of natural and artificially produced radioelements, health physics, metallurgy, refining techniques for key atomic-energy materials, etc.

2. An intensive and systematic survey of Brazil's natural resources, with prospecting activities directed toward locating such materials as uranium, thorium, graphite, cadmium, beryllium, lithium, zirconium, rare earths, etc.

3. The development of plants for the chemical separation of uranium and thorium from its ores and the formulation of plans for refining and fabricating materials needed in nuclear-reactor construction.

4. The installation of modern particle accelerators in various laboratories to broaden the scope of research and to aid the formation of groups of trained personnel.

Projects Underway

Although established only a year ago, the National Research Council already has several projects and investigations started. These include:

450-Mev synchrocyclotron. Plans for this accelerator, which will have a magnet 170 inches in diameter, are well advanced. Designed by Alberto, the synchrocyclotron will be constructed largely by local contractors (Volta Redonda steel plant and the Navy arsenal in Rio). It is to be installed in a special building on the University of Brazil's new campus on Fundão Island in Rio de Janeiro. The project will be under the scientific direction of Lattes and is the responsibility of a committee of Brazilian scientists and technicians. They were assisted in their planning by personnel from the University of Chicago, who went to Brazil to give the Lattes group the benefit of their experience with similar equipment.

Prof. A. Difini, is executive director of the synchrocyclotron project and of the Brazilian Center of Physical Research where the machine will be located. Capt. B. Lins de Barros is project coordinator.

Prospecting program. A systematic program of country-wide prospecting for uranium and thorium, with the most modern equipment and techniques known, is being developed. It includes radiometric surveys with Geiger counters in all old collections of minerals of the country, in sludge deposits of old mines, and over areas where radioactive ores have been found or where there are geological probabilities of such finds.

Two specialized companies, working under contract to CNPq and the Geological Survey [Departmento Nacional

da Produção Mineral (DNPM)], are doing aerophotogrametric, aeromagnetometric, and aeroscintillometric surveys over areas chosen by the people responsible for the geological research services of CNPq and DNPM.

Interesting deposits of thorium- and uranium-bearing minerals were located recently at Minas Gerais and Espírito Santo and are now undergoing careful study.

Separation techniques. Developing modern techniques for the metallurgical and chemical separation and refining of uranium and thorium is under study in a cooperative research program of the CNPq and the Institute of Technological Research [Instituto de Pesquisas Technológicas (IPT)] of São Paulo. The program includes a uranium pilot plant project under the direction of Prof. F. J. Maffei, who is in charge of IPT.

A similar cooperative program is starting at the Institute of Radioactive Research (Instituto de Pesquisas Radioativas), started with CNPq's help at the School of Engineering of the University of Minas Gerais. It involves the chemical, radiometric, and spectroscopic analysis of radioactive minerals, identification and quantitative measurement of the rare-earth elements by means of a large diffraction grating spectroscope, determination of geological time, and many correlated problems.

Fellowship program. Training of scientific and technical personnel is being stimulated by an extensive fellowship program inaugurated by CNPq. Fellowships are given to engineers, physicists, chemists, and biologists to take special courses in nuclear engineering, nuclear physics, chemical engineering, radioisotope chemistry, electrical engineering, electronics, radiobiology, etc., in the United States. This program will presently be extended to study in Canada and Europe.

Research Reactor First Goal

"All these preliminary activities," according to CNPq's scientific director Ribeiro, "have as the primary goal the construction of a research reactor, the location of which is now receiving careful study. Only as a second step of the program will we consider the construction of a power-producing reactor." The power reactor would be a type of breeder reactor suitable for industry and would "preferably" use thorium in combination with uranium.

Centers and Personnel

About 300 persons are actually working on the programs related to the development of atomic energy in Brazil. About 30% are scientific personnel in universities, 20% are engineers and technicians, 40% students (in undergraduate and graduate study), and 10% administrative staff members.

There are ten principal centers where either research, planning, or teaching is carried out. Foremost of these is the Brazilian Center of Physical Research in Rio. This is a private institution working under contract with CNPq, where electronic and nuclear equipment is now being planned and built for nuclear-physics and cosmic-ray research. The scientific staff of the center will operate a small synchrocyclotron model, now in construction at the University of Chicago, while awaiting completion of the 450-Mev accelerator described earlier.

At the University of São Paulo, both the Faculty of Science and the School of Engineering have research and study planned. A 30-Mev betatron is already in operation, and a Van de Graaff generator is scheduled for completion this month.

Other centers include the National Institute of Technology (electrical engineering department), in Rio; the Institute of Technological Research (chemistry and metallurgy departments), in São Paulo; the geological and chemical branches of CNPq and the National Geological Survey (joint program); the University of Brazil (present work involves training scientific and engineering personnel for future specialization in the nucleonics field), in Rio; the "President Vargas Factory" (a chemical plant), at Piquette; the Technical School of the Army, in Rio; the new Institute for Radioactive Research, in Minas Gerais; and the Biophysics Institute of the University of Brazil (program under way on biological protection against radiation hazards), in Rio.

Theoretical nuclear research is going on in various schools and universities throughout Brazil, but it is given special attention at the Universities of Brazil and São Paulo and at the Brazilian Center of Physical Research.

STUDIES with São Paulo's 30-Mev betatron include experiments with new type of target for X-ray production

Cosmic-Ray Research

Brazilian physicists are well known for their contributions to our knowledge of cosmic-ray interactions. The University of São Paulo group, whose work began in 1935, was responsible for the discovery of penetrating-particle showers (G. Wataghin, M. D. S. Santos, O. Sala). Study of these showers is being continued by A. Wataghin and G. Schwachheim, who recently made new, interesting observations at Morococha in the Peruvian Andes.

The discovery of heavy mesons by Lattes, Occhialini, and Powell, in 1947, resulted from studies made with nuclear plates exposed by Lattes at Chacaltaya high in the Bolivian Andes. Now Lattes' group at the Brazilian Center of Physical Research, under an arrangement with the University of San Andrés in La Paz, Bolivia, is working on further research at Chacaltaya, using new nuclear emulsions, cloud chambers, and counters. This program is being carried out with the cooperation of Occhialini and Camerini (under a UNESCO contract), Escobar of Bolivia (University of San Andrés), and Schein (University of Chicago).

Australia . . .

With U. S. export agreements in hand, the Australians have been pressing their uranium-mining activities. All atomic work is about to come under formal government control in Australia, including a nuclear-research program just getting underway

MELBOURNE—The Australian government will very shortly announce several important decisions on its attitude toward the development of its uranium deposits and the industrial application of atomic energy in Australia. These decisions embrace the creation of an autonomous atomic energy authority to supervise all Commonwealth mining, processing, purchases and sales of uranium, as well as development and research connected with atomic energy and its applications. It is believed that H. G. Raggatt, secretary of the Ministry of National Development, will head the authority.

Two things brought this organization about: (1) The discovery of what appear to be rich deposits of uranium in Australia has prompted certain lines of research based on the assumption that large quantities of uranium will be available at a reasonable price. (2) Australia has an undisputed need for a source of cheap, easily obtainable power. South Australia, for instance, sees in nuclear energy the only solution to its troubles. In fact, several prominent Australians have asserted that only the introduction of nuclear power can assure the development of Australia.

Uranium Deposits

Two major fields with promising uranium-ore veins are being developed.

The more advanced work is at Radium Hill in South Australia where, however, the grade of uranium is poor. It is the aim of the South Australian government to use these deposits ultimately for nuclear-power development. The U. S. Export-Import Bank is helping to finance development of this field, and technical assistance has been provided by American mining engineers. A pilot plant will be built in Adelaide to process Radium Hill ore. The operation of this plant, it is said, will determine the size of a larger refining plant to be built at Port Pirie.

The second major field is at Rum Jungle, Northern Territory. The Zinc Corporation has been entrusted with developing this field. As for the grade of uranium at Rum Jungle, it is high, but climatic and transportation difficulties are enormous.

The great problem is whether uranium ore should be exported or refined locally for export to the U. S. It is argued that future application of atomic energy for industrial purposes would be facilitated if the second course were adopted. According to a statement by Australian Prime Minister Menzies, a uranium deal between Australia and the U. S. is "about to be completed and an agreement should be signed in the very near future." It was learned authoritatively that Australia would receive a "good" price under the agreement, which would also provide that the U. S. replace uranium it got if or when needed for Australian industrial use.

Industrial Power

Howard Beale, Minister of Supply, has told the Australian House of Representatives that Australia has "not lost sight of the fact that quite apart from selling ore to our allies there is a future in Australia for industrial atomic development."

Australian scientists expect that its first nuclear-power reactor will be built in South Australia before 1957.

Support for Research

The Australian government is sparing no expense to insure that its nuclear scientists have everything they need for their research. In a country very conscious of its dollar expenditure, this is a special sign of grace.

To concentrate the research in one place, the government established and is strongly supporting a Research School of Physical Sciences at the Australian National University in Canberra. Although present government plans are directed to keep down most other expenditures, no restrictions have been placed on the funds needed to develop this school. Prof. Marcus Oliphant is in charge of the school, where a 2-Bev proton cyclo-synchrotron is under construction. A 1.2-Mev accelerator went into operation there early this year and was described in an article in the May, 1952, NUCLEONICS. Prof. E. W. Titterton, who wrote the article, is in charge of the school's department of nuclear physics.

In addition to Canberra, research is under way at the university at Melbourne and at the Woomera desert-station of the British Ministry of Supply.

Several Australians are in England working on atomic-energy problems, and they are expected, in time, to join the research efforts in their native country. At least one Canadian scientist is coming to do research, and the tendency is to entice more Canadian nuclear researchers to work in Australia.

India . . .

Lacking the larger tools for nuclear research, India is taking advantage of its geographical position to do advanced cosmic-ray research, and working out plans to develop its raw materials resources. Funds for extended nuclear research are lacking

K. S. KRISHNAN: is member of India's AEC, heads New Delhi lab

NEW DELHI—Indian scientists think their country will soon be capable of building a medium-size research reactor. According to K. S. Krishnan, director of the National Physical Laboratory at New Delhi and one of the three members of the Indian Atomic Energy Commission, such a reactor is possible "within two years."

Their optimism can be attributed, in part, to the discovery, within the past four years, of new deposits of uranium-bearing ores which, when exploited, will make India self-sufficient in uranium. This, together with the advances made in cosmic-ray research during the same period, is what Indian nuclear scientists consider their most significant development in the atomic-energy field.

The Indian government created its Atomic Energy Commission in 1948. Krishnan and his two fellow-members, H. J. Bhabha, director of the Tata Institute of Fundamental Research, and S. S. Bhatnagar, secretary to the Ministry of Natural Resources and Scientific Research, are responsible to Prime Minister Nehru.

Since its inception in 1948, the commission has operated on a four-fold policy, stated, in the words of Bhabha, its chairman, as: "(1) To survey the country for raw materials, (2) to take steps to develop these materials industrially, (3) to set up a nuclear reactor for experimental purposes within five years, and (4) to promote fundamental research in its laboratories."

Emphasis on Cosmic Rays

Indian physicists are faced with the fact that their country may never, for economic reasons, be able to compete with other countries in the field of elementary-particle physics through the use of large accelerators.

India's decision to concentrate on cosmic-ray work, Bhabha says, "has been fully justified, for valuable new information has been obtained about the behavior of elementary particles at energies which lie far beyond the scope of even the largest accelerator." The fact that the magnetic equator passes through Indian territory gives India an immense potential advantage in this field.

Projects and Centers

The main centers at which nuclear research is being undertaken are Calcutta, Bombay, Ahmedabad, Aligarh, Delhi, and Gulmarg in Kashmir, where a high-altitude observatory has just been established under the joint auspices of the Aligarh and Kashmir universities. All this research is subsidized by the Indian government.

Probably the most active and certainly the best equipped of the Calcutta centers is the Institute of Nuclear Physics, which, under its director, M. N. Saha, adheres closely to pure nuclear research, as distinct from cosmic-ray work. It possesses a 37-inch cyclotron—the only one in India.

The principal headquarters not only of cosmic-ray research but of all atomic-energy investigations in India is the Tata Institute of Fundamental Research in Bombay. The nuclear physics section of the Tata Institute is investigating the possibility of producing heavy water and building an accelerator. A 250-kev Van de Graaff generator has been built, and a large one, capable of producing 1-Mev deuterons, is under construction.

Mining Activities

A large part of the Indian effort in the atomic energy field concerns the survey, mining, and exploitation of uranium-bearing minerals. Deposits of low-grade uranium ore discovered in the State of Bihar in the last two years are thought to be sufficient to make India independent in uranium when exploited. Actual mining is expected to commence soon.

This year, too, a new plant at Alwaye in Travancore-Cochin, owned by the government company, Rare Earths, Ltd., has started processing monazite. The Alwaye factory is not yet at the stage of extracting thorium or uranium from the monazite; this will take a year more, and involves the erection of a second plant.

The Atomic Energy Commission has initiated a program to study the properties of beryllium. Along with Brazil, India is a major source of beryllium.

Personnel But Few Funds

Indian scientists do not conceal the fact that the main hindrance to the progress of atomic research in their country is lack of adequate funds. Although the Alwaye factory is expected to produce enough uranium as a by-product within two years for a moderate-sized heavy-water reactor, it is doubtful whether the funds will be available within that time.

Qualified nuclear scientists in India number probably less than 100, but behind them many eager post-graduates are queuing for a place in the government program.

Determining Neutron Fluxes from a Pulsating Radiator

Counting-rate meters are usually calibrated with random sources such as Ra-Be. The same calibration factor can be used, in suitable flux-level ranges, for monitoring pulsed accelerators. Determination of the fast-neutron hazard around a 23-Mev betatron with a proton-recoil counting-rate meter is analyzed

IN EVALUATING the hazard associated with a fast-neutron source, it can be assumed that a pulsating source causes the same biological damage to personnel that would be caused by a random source distributing the same average flux.

The purpose of this article is to derive an expression giving the response of a counting-rate meter, designed to measure neutron flux from a random source, as a function of the average neutron flux from a pulsating source.

Counter Characteristics

In the case of fast-neutron measurement, counter tubes are frequently employed containing some hydrogenous material which acts as a source of highly ionizing recoil protons. If this type of counter tube is operated in its proportional region, the attached rate meter is usually biased to exclude current pulses due to gamma radiation and to record only pulses due to proton recoils.

Random neutron flux. These recoil proportional counters are designed to have a pulse-resolving time τ short enough so that when measuring purely random neutron fluxes within the range of interest, the counter tube is nearly always recovered from a previous recoil-proton pulse before the next pulse occurs. That is, τ must be much less than the reciprocal of the maximum average counting rate to be considered, which is estimable from a knowledge of the maximum flux to be considered and the average collision cross section. If this design condition imposed on τ is obtained, it is assured, when measuring neutron fluxes of random origin, that the counting rate of the meter is always proportional to the average neutron flux present.

Pulsating neutron source. However, suppose the problem is confronted of measuring the average flux of fast neutrons at a certain distance from a pulsating source of neutron radiation. Suppose further that the time duration of each pulsation of the source is less than the resolving time τ of the counting-rate meter, and that the time interval between consecutive pulsations of the source is greater than τ.

Since the resolving time of the counter is greater than the time duration of a group of neutrons passing through it, no more than one current pulse can be recorded in the counter by recoil-protons from this group of neutrons. This is directly opposite to the case of a randomly distributed source, in which, as mentioned before, the counter is nearly always recovered from a previous ionizing event in time to record the next one.

In the case of the pulsating source, at some flux level the counting rate will level off asymptotically toward a maximum counting rate equal to the pulsation rate. The counter thus could not be used for measuring flux levels of this magnitude from pulsed radiators. But perhaps at lower flux levels, which might correspond to the range of interest, the response of the counter to a pulsating source of neutrons is linear with intensity.

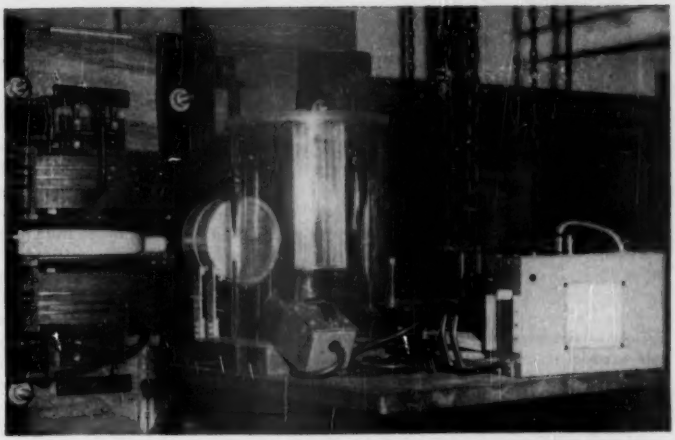
For a certain range of flux levels, the response of the counter to the pulsating source may be the same as if it were a random source, as in the case of a particular problem at the Naval Research Laboratory described later in this article. The counter can then be used with the ordinary calibration curve, or factor, for monitoring the pulsating source for neutron fluxes in this range.

Theory

In following the analysis, the reader should remember that the derivation is for the case in which the pulse duration of the radiator is less than the counter resolving time τ, and the time interval between pulses is greater than τ. Moreover, only flux ranges are considered which are below the point where coincidence losses become appreciable for random sources. These conditions conform to the cases usually met in practice.

Probability of detecting a single neutron. Assume for simplicity that the neutrons being measured are passing through a cylindrical counter in a direction parallel to its axis. Let the average collision cross section of the hydrogen nuclei in the counter presented to fast neutrons from the

By ALLEN BRODSKY
Naval Research Laboratory
Washington 25, D. C.



MONITORING a 23-Mev betatron (left background) with a portable proportional fast-neutron counter (center) and counting-rate meter (right)

pulsating radiator be σ in cm². Then, considering the counter to be a thin absorber, the average cross-section is given by

$$\sigma = \frac{\Delta F}{F n_t \Delta x} \text{ cm}^2 \qquad (1)$$

where ΔF is the number of neutrons removed from the beam per cm² per sec, F is the incoming neutron flux in neutrons per cm² per sec, n_t is the number of target protons per cm³ in the counter, and Δx is the length of the counter in cm.

For convenience, the effective thickness of the counter may be expressed as T target nuclei per cm², where $T = n_t \Delta x$, and Eq. 1 becomes

$$\sigma = \Delta F / F T \text{ cm}^2 \qquad (2)$$

or

$$\Delta F / F = \sigma T \qquad (3)$$

Equation 3 is the probability that a neutron passing through the counter will collide with a proton in the counter.

If the efficiency with which the counting circuit records recoil protons is given as ϵ counts per collision, then the probability p_1 that a neutron passing through the counter will cause a count to be indicated is

$$p_1 = \epsilon \Delta F / F = \epsilon \sigma T \qquad (4)$$

Meter response to random neutron flux. Suppose that the counter tube is exposed to a beam of neutrons parallel to its axis, the beam containing a random flux of n neutrons per cm² per sec. Then, if A is the cross sectional area of the counter tube in cm², nA neutrons pass through the counter per second. Since the probability that a neutron passing through the counter will cause a count is p_1, the flux of nA neutrons per sec through the counter will cause a response C counts per sec equal to $p_1 nA$. Substituting for p_1 from Eq. 4

$$C = p_1 nA = \epsilon \sigma T n A \text{ cps} \qquad (5)$$

Again it must be remembered that Eq. 5 is true because it is assumed that the counter is counting at a low enough rate that the probability p_1 that a neutron will be counted is not dependent on the recovery of the counter. This condition may be expressed in this case by $(\epsilon \sigma T n A)^{-1} \gg \tau$.

Meter response to pulsed flux. If a counter is exposed to a source which pulsates at the rate of R pulses per sec, and if, at a certain location, N neutrons flow through the counter tube per pulse, then the average neutron flux through the counter is NR neutrons per sec. Thus, if the cross-sectional area of the counter is A, then the average neutron flux n measured by the counter is

$$n = NR/A \text{ neutrons/cm}^2\text{/sec} \qquad (6)$$

To calculate the counter response C in counts per sec, the probability that a count will be obtained from the neutrons which pass through the counter during a single pulsation of the source must be determined. Then, this probability p_N of a count per pulse, times the pulsation rate R, will give the response

$$C = p_N R \text{ cps} \qquad (7)$$

If no proton-recoils above the bias energy are formed by a particular pulse, then no count will be obtained from that pulse. Since, for a single pulse of N neutrons, the possibility of obtaining a count and the possibility of not obtaining a count are exhaustive, the respective probabilities p_N and p_N' obey the relationship

$$p_N + p_N' = 1 \qquad (8)$$

The probability that an event will not occur in any of a set of N independent experiments is equal to the product of the probabilities that it will not occur in each experiment. Therefore, the probability p_N' that a count will not occur due to any of N neutrons passing through the counter may be expressed as a product of the probabilities, p_1', that a count will not occur for one neutron passing through the counter; that is

$$p_N' = [p_1']^N \qquad (9)$$

With $p_1' = 1 - p_1$, and Eqs. 4 and 9

$$p_N' = [1 - \epsilon \sigma T]^N. \qquad (10)$$

From Eq. 8

$$p_N = (1 - [1 - \epsilon \sigma T]^N) \qquad (11)$$

and, from Eq. 7, the response of the counter to a pulsating source which sends N fast neutrons through the counter per pulse is

$$C = Rp_N = R(1 - [1 - \epsilon\sigma T]^N) \text{ cps} \quad (12)$$

Finally, to obtain the response C in terms of the average flux n in neutrons per cm² per sec, the value nA/R from Eq. 6 may be substituted for N in Eq. 12, giving

$$C = R(1 - [1 - \epsilon\sigma T]^{nA/R}) \text{ cps} \quad (13)$$

Comparison of responses to pulsed and random sources. With Eqs. 13 and 5, the response of a counting-rate meter to a pulsating neutron flux may be compared to the response to a random flux of the same average value n. If the calculated values of C from Eq. 13 are the same as the calculated values of C from Eq. 5 over a range of flux values n, this means that over this range of n the counter response to the pulsating flux is the same as though the flux were random. Therefore, over this range of n, the counting-rate meter can be calibrated against random fluxes from a known random source, and can be used to measure pulsating fluxes from a pulsating source which emits neutrons having about the same average collision cross-section with protons.

In ordinary use, a counting-rate survey meter is exposed to a known random flux—n_1 neutrons per cm² per sec; a counting rate C_1 is obtained; and the ratio n_1/C_1, which from Eq. 5 is equal to the constant $(\epsilon\sigma TA)^{-1}$, is called the calibration factor f in neutrons per cm² per count. Then, this factor f is used, within the flux range for which C was designed to be directly proportional to n for a random flux, to determine an unknown random neutron flux from the counting rate of the instrument by the rearranged relationship of Eq. 5

$$C(\epsilon\sigma TA)^{-1} = Cf = n \text{ neutrons/cm}^2\text{/sec} \quad (14)$$

Equation 14 may also be used to calculate an unknown pulsating flux from a measurement of the counting rate, provided that the conditions of the previous paragraph are met.

Faster Response Determination

The comparison of counting rate versus flux by Eqs. 5 and 13 can be effected a little more conveniently by a simple manipulation. In fact, the calculation of the counting rates, C, can be obviated, since the main point of interest is the range of neutron fluxes for which the calibration factor can be used to obtain the pulsating fluxes.

In normal use, it is assumed that the counter is measuring a source of neutrons arriving in a random time distribution. Then, the average flux n_i indicated by the counter is found from the response C in counts per second with Eq. 14, where f is known from the calibration, as discussed previously. If a pulsed neutron flux is being measured, the indicated neutron flux is, according to Eqs. 13 and 14

$$n_i = Cf = fR(1 - [1 - \epsilon\sigma T]^{nA/R}) \quad (15)$$

Finally, from Eq. 14, $1/fA$ may be substituted for $\epsilon\sigma T$, and Eq. 15 becomes

$$n_i = fR(1 - [1 - 1/fA]^{nA/R}) \quad (16)$$

where n is the actual average value of the pulsated flux being measured, in neutrons per cm² per sec; n_i is the average flux value indicated by the counter, in neutrons per cm² per sec; f is the calibration factor of the counter in neutrons per cm² per count; R is the pulsation rate of the neutron source in pulses per sec; and A is the cross-sectional area of the counter tube in cm².

Equation 16 provides a compact relationship for calculating the neutron flux indicated by a counting-rate meter from the actual average flux level of a pulsed source with known values of f, R, and A. If calculations show, for a certain range of the actual flux n, that $n_i \cong n$, then the counter can be used in that range to find n. Thus, $n = n_i = C \times f$ neutrons per cm² per sec for the pulsating flux of neutrons. Moreover, if a curve of $n_i = fR(1 - [1 - 1/fA]^{nA/R})$ versus n is plotted, then the actual flux n can be estimated from n_i even at flux levels where n is not equal to n_i. However, at values of n approaching the point where the pulses of neutrons are so dense that they nearly always produce a count, the curve of n_i vs n begins to level off, and it becomes increasingly difficult to read values of the actual flux corresponding to values of indicated flux on the curve.

Sample Problem Analysis

The derivation of Eqs. 5 and 13, and Eq. 15, was required at the Naval Research Laboratory by the necessity of monitoring the fast-neutron hazard in areas surrounding a 23-Mev betatron. When operation of the betatron was begun, it was realized that high intensities of fast neutrons would be produced by the capture of high-energy X-rays in materials surrounding the target area. The X and gamma-radiation hazard in surrounding areas was monitored satisfactorily with various ionization-chamber-type meters that integrated the doses due to the pulsating photon fluxes and recorded them as steady average readings in terms of roentgens per hour. However, these ionization chamber instruments were not responsive to fast-neutron fluxes.

At the time the monitoring problem presented itself, the only portable survey instrument available at this laboratory for measuring fast-neutron fluxes exclusively was a methane-filled proportional counter.* A schematic diagram of the counter is shown in Fig. 1. The calibration factor had been determined periodically with a standard Ra-Be source. For all previous health physics purposes it had been reasonably assumed that this calibration was sufficiently accurate for the spectra of the other sources met in practice at NRL.

However, the validity of using this survey instrument for monitoring the pulsating betatron neutron fluxes was unknown. Therefore, a preliminary survey was made, care being taken to prevent the exposure of anyone to areas suspected of being dangerous. The counting-rate meter readings were interpreted later by the analysis described in this article.

Some further observations were necessary to determine whether the situation conformed to the theoretical conditions discussed earlier in this article. The intermittent beam of electrons emitted by the betatron had pulse durations of about 2 μsec, at a frequency of 180 pulses per sec. The velocity of fast neutrons in the Mev range is so great that the transit time of a group of neutrons in an area near the betatron could not have been more than about 3 μsec, and the frequency of the pulsating flux of neutrons would, of course, have been 180 pulses per

*G. S. Hurst, A portable fast neutron survey meter, ORNL-485 (1949). G. S. Hurst, R. H. Ritchie, H. N. Wilson, A count-rate method of measuring fast neutron tissue dose, *Rev. Sci. Instr.* **22**, 981 (1951).

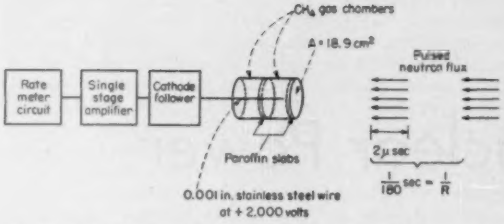


FIG. 1. Pulsating neutron measurement with a proportional counter

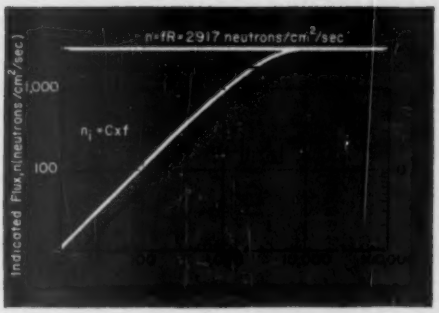


FIG. 2. Counter response vs actual betatron neutron flux

sec. Therefore, it had to be determined that the resolving time τ of the neutron counter was greater than 3 μsec and less than $\frac{1}{180}$ sec.

The resolving time τ was measured to be about 1,500 μsec when the instrument was operated on the medium scale, and about 500 μsec when the instrument was operated on the high scale. The resolving time on the low scale, however, was close to $\frac{1}{180}$ of a second, so it is not certain whether the present analysis holds for this scale. However, since the resolving time on the low scale is less than $\frac{3}{180}$ μsec, the actual response on the low scale could not have been less than $\frac{1}{3}$ of the response calculated herein from the assumption that 3 μsec $< \tau < \frac{1}{180}$ sec. Moreover, the low scale is needed only for a more accurate determination of low fluxes in the range less than the maximum permissible level for continuous 40-hour-per-week exposure. A flux level of 25 neutrons/cm²/sec has been considered the maximum permissible safe level for personnel working at this laboratory.

The resolving times were measured by both the two-source method and the method of observing successive pulses on an oscilloscope.

To justify the use of a meter calibrated with a Ra-Be spectrum of neutrons, it was assumed that no important error was involved in comparing the betatron spectrum to a Ra-Be calibration.* This assumption is further justifiable in the case described herein, since the counter response versus energy is rather broad in the energy range containing the major part of both the Ra-Be and betatron neutron spectra.

Calculations. Once the suitability of the meter had been established, Eq. 16 was evaluated over a range of average neutron fluxes to compare fluxmeter readings to the true average flux values. The results are plotted in Fig. 2.

A sample calculation of the fluxmeter reading n_i will be shown using the following values:

$n = 2{,}000$ neutrons/cm²/sec as the actual betatron flux;

$f = 16.2$ neutrons/cm²/count, measured by exposing the counter to a known Ra-Be source and dividing known neutron flux at a certain distance from the source by the counting rate obtained at that distance;

$A = 18.9$ cm², the cross-sectional area of the counter;

$R = 180$ pulsations/sec, the betatron pulse rate.

Substituting the above values of f, A, and R in Eq. 16, the indicated flux is

$$n_i = 16.2 \times 180 \times \left(1 - \left[1 - \frac{1}{16.2 \times 18.9}\right]^{\frac{2{,}000 \times 18.9}{180}}\right)$$

$$= 1{,}448 \text{ neutrons/cm}^2\text{/sec}$$

See the curve of Fig. 2 for other values of n_i vs n.

Discussion

In the example of the previous section, the use of the present analysis has demonstrated a case in which a recoil counting-rate meter can be used with the usual calibration factor for estimating betatron-produced neutron fluxes in the range from 10 to 1,000 neutrons/cm²/sec. Moreover, indicated readings outside of this range can be interpreted by the use of the curve in Fig. 2.

The theory presented here can be used also to design a neutron-recoil counting-rate meter for monitoring pulsed-accelerator neutron radiation conveniently. The range of linearity of such an instrument can be extended to higher flux values by increasing the value of the calibration factor f. This may be accomplished by proper design of the instrument—adjusting either or both of the parameters ϵ and D. Although such an increase in f might cause a very low sensitivity at low flux levels, the instrument could be designed to have several ranges to meet the needs of the user.

Although a discussion of slow-neutron measurement is not the purpose of this article, it might be well to mention that in cases where the fast-neutron flux near pulsed accelerators is at a safe level, the existing shield arrangement is usually such that any slow-neutron hazard is negligible. This is partly due to the fact that the maximum permissible slow-neutron flux is about 1,750 neutrons/cm²/sec for 40-hr-per-week exposure, compared to a fast-neutron permissible flux of 25 neutrons/cm²/sec.

An analysis similar to the one in this article can be made to determine the response of G-M counters to pulsating gamma-ray fluxes.

* * *

The author would like to thank Mr. T. A. Bergstralh, Mr. Luis F. Garcia, Mr. J. I. Hoover, Dr. F. N. D. Kurie, and Dr. L. Seren, for contributing many valuable suggestions toward the improvement of this article.

* J. S. Laughlin, NUCLEONICS **8**, No. 4, 5 (1951)

Progress Report on

Industrial Nuclear Power

Where do we stand today on industrial development of nuclear power?

Does industry want to explore the possibilities of this field?

NOW, FOR THE FIRST TIME since December 2, 1942, the date of the world's first nuclear chain reaction, we can get somewhat of a picture of how nuclear reactors may be exploited.

It was approximately two years ago that the Atomic Energy Commission approved the proposals of two industry teams to study the feasibility of building nuclear power plants. Since that time three more teams have made similar arrangements with the AEC.

These companies are carrying out pioneer ventures. Because of AEC control of all work on large reactors, previous industrial activity on such reactors has been in connection with the Government's program. But through this activity, a number of companies gained invaluable background.

Thus, in 1950, Monsanto's C. A. Thomas proposed the concept of the dual-purpose reactor—production of power plus byproduct plutonium. With the proceeds from the sale of plutonium to the Government as a subsidy, it might then be possible to operate nuclear power plants economically.

Shortly thereafter a number of other companies became interested in the possibilities of this idea. AEC then made arrangements for these companies to study the over-all problem including specific designs.

Main Problems

The principal questions which these groups have had to face are:

1. Is it worth spending any considerable sum of money at this time on the development of power reactors?

2. What might it cost to build a full-scale power reactor and associated facilities?

3. What type reactors would be best?

4. What political environment would be best suited to industrial development of nuclear power? More specifically, what changes in the McMahon Act would be necessary? Should such changes be made before or after industry starts spending its money on reactors?

Finding the answers to these questions has not been easy. No nuclear power plant has ever been built, so it isn't merely a matter of digging the needed facts out of existing engineering reports. Instead some highly imaginative thinking has been called for.

The Trends

To date, the trends in industrial thinking run somewhat like this:

There is an air of cautiousness. Until the costs involved and the market are more clearly defined, no major risks will be taken by industry. Instead there is the feeling that the Government should underwrite in one way or another the initial development stage.

This could be done by the Government's paying for the building of pilot-plant or full-scale reactors. Or the Government might guarantee to buy plutonium from the companies at a specified price for a specified number of years. Right now it appears that the AEC is not too anxious to get involved in either of these arrangements. At least one industry group plans to spend its own money and will not depend upon a guaranteed price for the plutonium it produces.

Reactor Types

When these studies first started, the dual-purpose reactor appeared to offer interesting possibilities principally because it was felt that the cost of power from a single-purpose plant could not come close to competing with conventional sources. Such a reactor could be built fairly quickly based on experience in the AEC program. As a result, the design developed would not be startlingly different from that used in the Hanford plutonium plants.

One important factor is that the companies want to get a unit in operation so that they could find out what the real engineering problems are. Thus this might be the first of a family of reactors.

There are two unsound aspects to this approach. One is the dependency upon an assured market for plutonium, something which is quite uncertain. The other is that the Hanford-type reactor for power purposes might be obsoleted by more advanced designs very shortly after it is built.

For the long-range haul, there is little disagreement with considering the breeder-type reactor to be the unit

about which central-station nuclear power will develop.

Atomic Energy Act

The provisions of the McMahon Act limiting industrial participation in nuclear power development do not appear to be impeding industrial interest at this early stage. If the barriers were let down, there would be no sudden influx of money into this field.

But there is very little disagreement about the fact that the Act should be changed. Actually the attitude is, "Is there any reason that the Act *shouldn't* be changed?" David Lilienthal, former chairman of AEC, advises industry not to invest money in the nuclear power field until the Act is changed. Philip Sporn, president of American Gas and Electric, says, on the other hand, that changes in the Act aren't really necessary until further technological advances have been made.

The AEC plans to submit to Congress early next year recommendations on how the Act should be revised.

Time Scale

Determining when we will have our first operating nuclear power reactor is still a matter of astute crystal gazing. However, one industrial group working in this field has set a schedule for itself something like this: preliminary design will take three years; final design one to two years; construction another one to two years. Thus, this group expects to have a completed reactor in five to seven years.

Reports of Study Groups

Four groups of companies have completed at least a year's study of the problems outlined on p. 40 and have submitted reports to the AEC. These groups are: Monsanto and Union Electric of Missouri; Detroit Edison and Dow Chemical; Public Service of Northern Illinois and Commonwealth Edison; and Bechtel Corp. and Pacific, Gas and Electric.

These reports are still secret. A subcommittee of AEC's board of "senior responsible reviewers" met last month to consider whether or how parts of these reports might be declassified.

However, enough information is available now so that we can get a picture of where these groups stand.

Monsanto–Union Electric. This group is not yet ready to invest its money in the building of a power reactor. It has proposed that the AEC build a pilot plant for preliminary experimental work. In addition, it prefers delaying building a reactor until a satisfactory solution is found to the legal problems of private ownership of nuclear power and limitations on private patent rights.

Detroit Edison–Dow. This group has made the very important statement that it does not feel that a definite price must be established in advance for the sale of byproduct plutonium, although it does not overlook the need to sell this plutonium. It expects that there will not only be a possible plutonium market for weapons purposes, but that there will also be a market for the excess fuel to meet the requirements for mobile reactors and of an expanding nuclear power industry.

The objective of this group is the development of a fast breeder reactor, providing a high coolant temperature and using easily fabricated fuels, closely integrated with a low-cost separations process.

A principal objective of the group has been the selection of an approach consistent with the long-range requirements but capable of early development. The reactor will be liquid-metal cooled and will use solid fuel elements. They believe that the best approach is early construction of a full-size unit.

They assume that an exclusion area must be provided for the first reactor. One possibility for building such a unit, they feel, at minimum construction and exclusion area costs, would involve locating the reactor and appurtenances on a barge or ship. This would permit construction to be done in a shipyard, thus simplifying security requirements and requiring a minimum of new construction facilities. When the reactor is built, the base would be floated to and anchored or sunk at a location which provides adequate exclusion area. Shielding would be provided by steel tanks filled with sand and water.

Initially, only the reactor with integrated separations facilities would be built, to minimize first costs. Heat produced could be readily "dumped" in such a location, and electrical generation and transmission facilities could be added later when desired.

Commonwealth Edison–Public Service. This group feels that a large-scale project would be necessary to average down costs to achieve economic justification. Because utilities do not have venture capital, these companies feel that the Government should pay for the reactor part of the nuclear power plant and the companies should pay for the conventional power facilities outside of the reactor.

Bechtel–P. G. & E. This group has only stated that it is interested in breeder-type reactors.

MATERIALS FOR REACTORS

IN 1948, estimates were made of the amounts of major materials needed to construct a reactor. Thermal reactors would need 100 lb of boron for controls; 100 tons of beryllium and 400 tons of graphite for moderator and reflector; 5 tons of bismuth, 5 tons of lead, and 1,000 ft³ of helium for coolant; and 100 lb of cadmium for controls.

An epithermal reactor would need 5 tons of mercury, 1 ton of sodium, and 1 ton of potassium for coolant. ("The Science and Engineering of Nuclear Power," C. Goodman, ed., vol. 2, p. 15, Addison-Wesley Press, Cambridge, Mass., 1949.)

TODAY, these estimates still apply ***for construction of reactors of the type in vogue in 1948.*** But a great deal of progress has been made since then both in the increased production of U^{235}, thereby making enriched reactors much more attractive, and in developing new reactor materials.

Lead, bismuth and sodium still appear near the top of the list as liquid-metal coolants. However, fused salts and tin alloys should also be included. Among the most important developments in fuels, coatings and structural materials are highly refined zirconium and new alloys of uranium and plutonium. Stainless steel (type 521) and aluminum (type 2S) continue among the best structural materials.

FIG. 1. Loading multicurie source with material to be irradiated

FIG. 2. Attaching canister to carrier for insertion in source

Use of Fission Products for Insect Control

Insect infestation of finished and packaged products can be controlled with fission-product gamma rays. In tests with Co^{60} on six species of insects, reproduction was inhibited with 16,000–32,000 r; 64,400-r doses are completely lethal

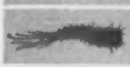
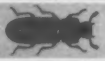
By CHARLES C. HASSETT
and DALE W. JENKINS
Entomology Branch
Chemical Corps Medical Laboratories
Army Chemical Center, Maryland

ESTIMATED yearly damage to stored products in the United States alone is over one billion dollars.* Since many products cannot be subjected to heat treatment, and insecticides are undesirable contaminants of finished foodstuffs, the huge store of radiation available in fission products could be put to use in the sterilization of foods and drugs and in the control of insect infestations of food, clothing, and wood products (*1, 2, 3, 4*).

Almost no data are available concerning the lethal effects of isotope radiation on insects. Before attempting to use radiation from reactor wastes, it is necessary to know the lethal dose. This report describes experiments designed to show the effects of high-intensity gamma radia-

* Unofficial estimate from the Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture.

TABLE 1 — Insects Subjected to Radiation in the Cobalt-60 Source.

	Scientific Name	Common Name	Stage irradiated	Material damaged
	Attagenus piceus	Black Carpet Beetle	larvae — adult	Carpets, clothing, dried foods
	Dermestes ater	Larder Beetle	larvae — adult	Fur, skins, meat
	Lasioderma serricorne	Cigarette Beetle	adult	Tobacco, upholstered furniture
	Sitophilus oryzae	Rice Weevil	adult	Wheat, corn, most grains
	Rhyzopertha dominica	Lesser Grain Borer	adult	All grains and seeds
	Tribolium confusum	Flour Beetle	adult	Flour and dried food products
	Lyctus planicollis	Powder Post Beetle	adult	Lumber, houses, furniture
	Drosophila melanogaster	Vinegar Fly	egg — pupa — adult	Fruit, food

tion from radioisotope sources on insects troublesome to grain, tobacco, and similar industries.

Many investigations have been made on the effects of radiation on various kinds of insects (*5*). Most work has been concerned with the production of mutations for genetic study, usually with the vinegar fly *Drosophila* or similar forms. Some research, however, has been concerned with doses which prevent reproduction (*6*) or produce lethal effects. Packard (*7*), using X-rays, found that 180 r killed 50% of young (approximately 3-hr) *Drosophila* eggs. Dittrich *et al.* (*8*) found that X-rays were more effective than fast electrons when *Drosophila* eggs over 3 hr old were treated. In another study (*9*) similar results were obtained from the irradiation of pupae. These two papers and others also bring out the important fact that resistance to radiation increases steadily with development, for the LD-50* was 200 r for 3-hr-old eggs, 500 r for 4-hr eggs, 810 r for 7.5-hr eggs, and 2,800 r for pupae (*5*). Many recent papers (e.g., *10, 11, 12*) deal with other aspects of the problem, particularly the relative effectiveness of X-rays and some of the higher-voltage particles.

* LD-50 = dose lethal to 50% of the test organisms.

Lethal Effects of γ-Rays

Preliminary experiments were carried on at Army Chemical Center, early in 1951, using tantalum-182 as a source. With these results as a guide, further experiments were performed by exposing insects to a kilocurie cobalt source at the Fission Products Utilization Project, Brookhaven National Laboratory.

Irradiation with Ta^{182}. Pellets of tantalum were packed around two sides of a well with an approximate size of 10.5 cm × 3.0 cm × 22.5 cm deep. Insects were put into shell vials which were loaded, six at a time, into a light metal rack and lowered into the well. Initial measurements with an ionization chamber of the radiation in this well showed an intensity of 1,300 r/hr, or about 30,000 r/day.

Some of the results we obtained from these experiments were as follows: 90% of adult *Drosophila* were killed by exposure to 84,000 r; 14% of 60-day-old *Blatella germanica* (German cockroach) were killed by 72,000 r. Adult flour beetles, *Tribolium confusum*, were exposed to various levels of radiation with the following results: 80% were killed by 110,000 r, 90% were killed by 140,000 r, 100% were killed by 196,000 r; and no deaths occurred in the unexposed controls.

These results, though indicative of the levels required to produce significant lethal effects, were considered to be unsatisfactory because of the long exposures needed. Resistance to radiation increases as the insects develop (*5, 8*). Two doses, each of the same number of roentgens, are not equivalent if one is of long duration, the other short. During a long exposure, a larval insect may go through several developmental stages.

Kilocurie Co^{60} source. This source (*13*) consisted of a Co^{60} tube which delivered approximately 193,000 r/hr* to objects placed in its lumen.

The insects to be irradiated were put into shell vials with a supply of suitable food. For most species this was flour or corn meal; for *Drosophila* it was the standard agar-corn meal-

* Measured by the staff of the Fission Products Utilization Project by chemical dosimeter and ionization chamber.

TABLE 2—Percentages of Mortality for Six Species of Insects after Exposure to Various Levels of Gamma Radiation

Species	Dose in roentgens	No. of insects exposed	Percent mortality																						
			Time after exposure (days)																						
			1	2	3	4	5	6	7	9	12	15	14	16	18	20	21	23	26	29	33	40	48	56	60	70	80
Attagenus larvae	Control	196	—	1	—	—	1	—	1	—	—	—	—	1	—	—	2	—	—	7	—	7	7	—	—	—	7
	16,100	105	—	0	—	—	—	—	—	—	—	—	—	0	14	18	—	—	35	40	42	50	54	60	71	85	100
	32,200	110	—	0	—	—	—	—	—	—	0	—	—	2	28	—	37	—	53	57	63	64	67	72	86	100	
	64,400	102	—	0	—	—	1	—	—	—	1	—	—	1	33	—	40	—	47	50	51	67	78	90	100		
	128,800	100	—	1	—	—	7	—	11	—	54	—	—	72	88	—	96	98	100							
	193,000	102	—	40	—	—	80	—	90	—	97	—	—	100												
	257,600	100	94	98	100																					
Lasioderma adults	Control	128	—	46	—	—	78	84	89	—	96	—	—	100												
	16,100	106	—	43	—	—	72	83	91	—	100															
	32,200	99	—	27	—	—	61	82	91	—	100															
	64,400	100	—	51	—	—	72	79	89	—	100															
	128,800	93	—	58	—	—	72	84	90	—	98	—	—	100												
	193,000	103	—	62	—	—	85	90	94	—	100															
	257,600	98	—	97	100																					
	322,000	100	—	100																						
Sitophilus adults	Control	100	—	0	—	—	8	37	83	—	94	—	—	100												
	16,100	100	—	2	—	—	93	—	94	—	100															
	32,200	100	—	22	—	—	36	80	87	—	100															
	64,400	95	—	37	—	—	88	—	100																	
	128,800	95	—	59	—	—	100																			
	193,000	100	86	100																						
	257,600	100	99	100																						
Rhyzopertha adults	Control	366	—	1	1	—	1	—	—	—	—	—	—	—	4	—	6	—	—	7	—	10	11				
	16,100	111	—	5	5	—	6	—	—	7	—	—	—	—	23	37	—	51	61	70	80	90	100			
	32,200	97	—	4	7	9	11	—	—	—	12	—	—	—	28	44	—	65	78	87	98	100				
	64,400	132	—	4	5	11	12	—	—	—	16	38	—	65	86	96	—	100								
	128,800	112	—	6	13	30	46	55	83	100																
	193,000	110	—	25	46	82	97	100																		
	257,600	100	—	75	84	100																				
	322,000	102	100																							
Tribolium adults	Control	213	—	2	3	—	4	—	—	5	5	6	—	—	—	6										
	16,100	88	—	2	3	5	—	—	—	8	49	100														
	32,200	102	—	3	4	—	5	—	—	11	65	100														
	64,400	105	—	4	5	6	9	11	12	43	93	98	100													
	128,800	119	—	8	14	15	19	31	76	100																
	193,000	125	—	16	60	84	94	100																		
	257,600	100	—	83	100																					
	322,000	110	100																							
Dermestes larvae	Control	97	—	0	—	—	1	—	—	2	4	7	—	—	9	12	17	—	—	23	pupae			adults			
	16,100	42	—	2	—	—	5	—	—	10	19	—	—	—	—	29	—	50	—	55	} died during pupal stage						
	32,200	44	—	5	9	—	20	27	30	50	59	80	—	—	—	—	82	—	—	—							
	64,400	58	—	9	29	67	90	100																			
	128,800	41	—	10	78	100																					
	193,000	52	—	33	98	100																					
	257,600	44	—	41	100																						
	322,000	50	—	48	100																						
Dermestes adults	Control	65	—	2	5	14	26	32	46	68	91	100															
	64,400	91	—	11	18	22	42	56	69	96	99	100															
	193,000	94	—	78	96	100																					
	322,000	100	100																								
Attagenus adults	Control	51	—	14	31	33	39	45	—	55	—	67	84	—	92	96	—	100									
	64,400	32	—	9	28	41	53	63	—	91	—	100															
	193,000	50	98	100																							
	322,000	50	100																								

syrup rearing medium. The *Lyctus* beetles were not provided with any food, since they normally eat very little.

The vials were put, six at a time, into a canister which was then lowered into the cobalt tube (Figs. 1 and 2). With the exception of *Drosophila*, which was included for comparison with other experiments, the insects irradiated at Brookhaven are serious pests of stored products of various kinds (Table 1).

In the first series of experiments, seven graded doses were given to groups of each species as follows: 16,100 r, 32,200 r, 64,400 r, 128,800 r, 193,000 r, 257,600 r, and 322,000 r.

In the second series, doses of 8,050, 16,100, 32,200, and 64,400 r were given to groups of adult *Lyctus planicollis* and *Drosophila melanogaster*.

Table 2 and Figs. 3, 4, and 5 show the results of the first series. After

exposure to 322,000 r, nearly all insects were dead, or apparently dead, only a few being able to move 12 hr after exposure. None showed any signs of recovery, and the most resistant form, larvae of *Dermestes*, were all dead by the third day after irradiation.

High percentages of each species were killed within 24 hours after exposure to 257,600 r and only a few individuals of *Rhyzopertha* survived the third day. A dose of 193,000 r was also very effective, and only a few individuals of three species survived longer than 5 days.

At 128,800 r, lethal effects varied more noticeably. All individuals of *Sitophilus* were dead on the fifth day, while on the seventh day, 75% of *Tribolium* were dead, but only 11% of *Attagenus* larvae. The death rate of the last species increased after this, however, and 60% were dead a week later, while of the few individuals remaining, all were dead at 26 days.

Figure 5 gives the mortality curves for all Series-1 insects exposed to 64,400 r. These curves show that most of the insects died during the first week following exposure and that only *Rhyzopertha* survived into the third week. Under large-scale operating conditions 65,000 r would probably be a satisfactory minimum dose for quick killing. Many insects would receive more than the minimum dose and death would be more rapid.

Two lots of *Drosophila* were exposed during the first series of tests—one at 193,000 r and one at 64,400 r. All the flies subjected to the higher dose were dead in two days, but some of the others survived up to three weeks. A few eggs were laid by these flies, but none hatched.

In the second series, additional *Drosophila* were irradiated for the purpose of ascertaining the dose at which inhibition of reproduction occurs. The flies used in this series were between one and two days old when they were irradiated and all survived for 2–3 weeks afterward so that no immediate lethal effects were noticeable. No attempt was made to count these flies as was done with the insects of Series 1. In spite of good survival, however, it was found that flies laid no eggs after exposure to 64,400 r, several nonviable eggs were laid after 32,200 r and 16,100 r, but flies exposed to 8,050 r laid a great many eggs after a four-day lag following irradiation;

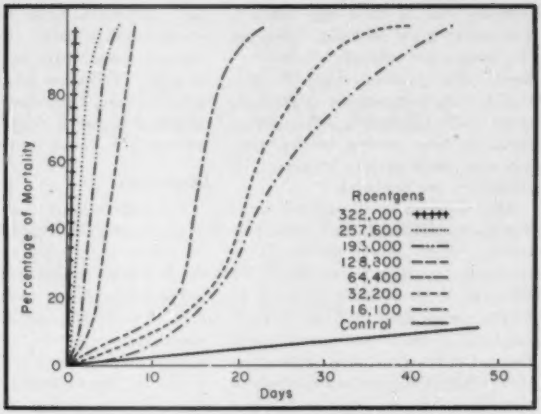


FIG. 3. Mortality rates of adult *Rhyzopertha* exposed to γ-rays

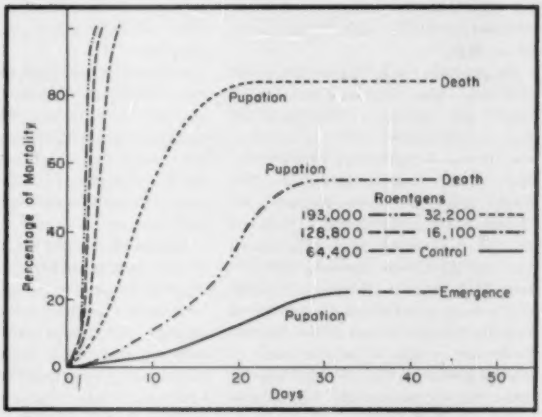


FIG. 4. Mortality rates of larval *Dermestes* exposed to γ-rays

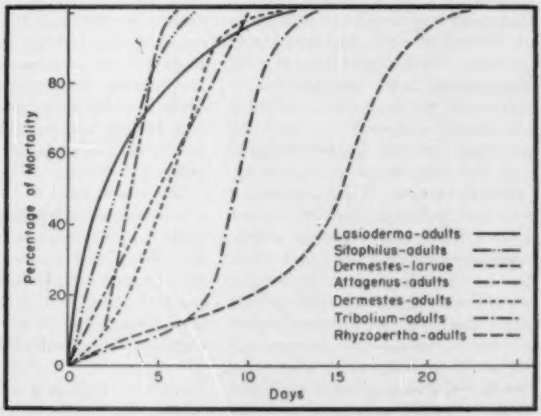


FIG. 5. Mortality rates of six species after exposure to 64,400 r

relatively few of these eggs hatched. The larvae grew normally, following the usual time schedule of development. The resulting adults (F1 generation) were apparently normal in structure and function. When transferred to fresh rearing bottles, they laid eggs freely and an abundant F2 generation was produced.

Also included in the second series was *Lyctus planicollis*, the powder post beetle. These insects proved to be relatively resistant to radiation, for although most of those exposed to 64,400 r were dead after seven days, nearly all of the others survived until the end of the third week after exposure. Since the controls died at about the same rate, no significant killing occurred at less than 64,400 r. *Lyctus* beetles exposed to 32,200 r or more laid no eggs, but the controls and those exposed to 8,050 r and 16,100 r laid many eggs.

In general, the killing power of the radiation was clearly demonstrated, but because optimum conditions could not be maintained while transporting the insects to and from Brookhaven, some of the controls died within two weeks after the tests started. Although there is little doubt that the treated *Lasioderma* were affected by the radiation, the controls survived very little longer. *Sitophilus* controls died almost as rapidly as the irradiated insects, but were somewhat hardier than *Lasioderma*. The survival of control groups of the other species was satisfactory, particularly for *Rhyzopertha* and *Tribolium*.

As in nearly all such experiments, this one posed the problem of deciding what constitutes death. A vivid example of this difficulty was encountered in *Lyctus*. Following irradiation, they were returned to the Maryland laboratory, and two days after irradiation an attempt was made to count the survivors. All the irradiated insects were found to be quiescent, and appeared to be dead. Upon re-examination the following day, they were active. There was evidently a temporary knockdown with *Lyctus* which has not been seen in other species. Many insects appear to be lifeless at a given time, but can be stimulated to activity, or will become spontaneously active. Separating living from dead insects therefore requires a great deal of care. Even after recovery from the initial knockdown, *Lyctus* proved to be so difficult to judge that no exact counts could be made. Other species, however, were fairly easy to judge, especially *Tribolium* adults and *Dermestes* larvae. Before any insects were discarded as being dead, every effort was made to detect some sign of life.

Discussion

The data indicate that the amount of gamma radiation necessary for killing insects is much less than is needed for bacterial sterilization, which requires 1,000,000 r or more (*4*), but far higher than the lethal doses for mammals.

Two methods of insect control are available. Fast-killing doses of 65,000 r, which were quickly and completely lethal, would stop the damage of heavy infestations. Light infestations, however, could be controlled by doses of lesser intensity which would stop reproduction.

Extensive insect damage to materials can be prevented without excessive exposure to radiation, which is especially important in treating foodstuffs. Extremely high doses may produce flavor changes (*1, 3*). Packaging prior to treatment would prevent reinfestation.

Design of irradiation unit. A conveyor system suitable for passing material through a radiation field will have to be capable of delivering a fixed minimum dose to all material, provide sufficient shielding to protect personnel and permit easy replacement of radioactive material.

The amount of radioactive material needed will be determined by the minimum dose desired, quantity and density of material to be treated, source design, and the rate of decay of the isotope. Unless transportation and handling problems can be overcome, it would seem preferable to use long half-life isotopes, thus reducing the need for frequent renewal of radiating elements.

The exact form of a source will depend on the most efficient design for a given application. The material could be passed between two source layers or over both surfaces of a single source layer. In a tentative design for a penicillin sterilizer, it has been suggested in a Stanford Research Institute report (*1*) that a conveyor describe a spiral path around a pipe containing radioisotopes.

Induced radiation is encountered only with neutron sources. With gamma radiation, no secondary radiation would be induced in the treated material.

Personnel protection is the primary design problem. As soon as the shape and intensity of the source are determined, shielding can be dealt with adequately. Both the conveyor system and the source must be such that repair of mechanical components and the replacement of exhausted isotopes entail no hazard to personnel.

Cost of radioisotopes. Whether or not such units are built depends on solving the problem of producing suitable concentrated fission waste at a low price per curie.

The Stanford report (*1*) includes estimates of the cost of building and operating a unit for the sterilization of penicillin, using Ce^{137}, and also the costs of semirefined and separated fission products for other possible uses. Semirefined products, which are partially concentrated by removal of inactive substances, are estimated at from $0.20 to $2.00 per curie. If it is economically feasible to sterilize drugs by radiation, it appears equally feasible to destroy insect pests in the same way, since very much smaller quantities of energy are required to achieve satisfactory control of insects.

* * *

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Assay of Mixed Radioisotopes

Simultaneous use of two or more different tracers can greatly aid biological research. The basis of the technique is the difference in radiation characteristics. As an example, the assay of Na^{24} and K^{42} is described

By J. F. TAIT and E. S. WILLIAMS
Department of Physics Applied to Medicine
The Middlesex Hospital Medical School, London, England

IN BIOLOGICAL SYSTEMS, it is often desirable to examine the fate of several elements. The difficulty and uncertainty of the interpretation of such experiments can be greatly reduced by simultaneous use of different tracers.

The value of using multilabeled molecules in investigation of the metabolism of compounds has already been proven (*1–5*). The labeling of a molecule at different positions by different isotopes may help to solve problems often encountered in tracer investigations, such as whether

1. Different parts of the molecule are metabolized in a similar manner.
2. Exchange processes occur in the particular investigation.
3. The metabolism of a part of the molecule depends on the mass of the isotope used. This is of particular value in the use of molecules labeled with isotopes of hydrogen.

Such problems could be solved by investigation of the metabolism of a compound, labeled in a certain way, when used with one group of animals, followed by a similar investigation with the same compound labeled in a different manner and used with another group of animals.

It is, however, impossible to repeat biological investigations under exactly the same conditions, and unless large numbers of animals are used the result will be unreliable. In clinical studies, the repeat experiment would have to be carried out on the same subject after an interval of time, during which the conditions of the original experiment might have changed.

For the same reasons, mixed isotopes may be of great value in biological investigations even though they are not incorporated in the same molecule. It is, for instance, very convenient and useful to determine simultaneously the sodium and potassium space of a patient. The adoption of such a technique in bioassay methods should lead to great economy in the use of animals.

One of the authors (J. F. T.) and his collaborators have been particularly concerned with the development of a microbioassay method for the effect of adrenal steroids on mineral metabolism (*6, 7*). The method finally adopted measures the effect of these steroids on the urinary Na^{24}/K^{42} value of adrenalectomized rats after preliminary injection of a mixture of these isotopes. Although particularly concerned with the assay of mixtures of Na^{24} and K^{42}, the following treatment of the problems involved is of general applicability to the assay of two mixed isotopes.

In general, for such a technique, it is preferable to employ two or more isotopes which may or may not be incorporated in the same molecule, but which have such dissimilar radioactive characteristics that the amount of each isotope can be estimated by physical procedures only.

In developing a technique for a particular biological investigation, one must choose the most suitable isotopes and the optimum design of a particular differential detection method for these isotopes.

Choice of Method

The particular method of differential detection must depend on some aspect of the isotopes' differing radiation characteristics.

Different decay rates. If the decay rates differ, a measurement of the activity of the mixed specimen at different times will enable the contribution of each isotope to be estimated by solving the resulting simultaneous equations. This method, used successfully by many workers, is of particular value when the decay rates are widely different (*8*).

However, the apparent decay rate of a specimen may depend on its physical state (*9*). This may be due to exchange phenomena, to emission of a radioactive compound in gaseous form, or to variation in release of a radioactive product from the specimen.

For this reason the method is unreliable when the decay rates of the isotopes are nearly equal.

Different radiations. If one of the isotopes in a mixture emits radiation which the others do not, it is relatively simple to assay this isotope. The extreme example of this is use of a stable isotope mixed with radioisotopes (*2*). Other examples are detection of α-emitter At^{211} in the presence of β- and γ-emitter I^{131}, and detection of X-ray emitter Fe^{55} in the presence of β- and

γ-emitter Fe^{59} (*10*). If the isotopes and detection equipment are available, the differing radiations should be the basis of the method.

Different radiation energies. Since most isotopes emit both β- and γ-rays, the differing energies provide the only method for many mixtures, including those of Na^{24} and K^{42}. Differences in the energies of either the β- or the γ-rays can be used. For β-rays, a G-M counter is generally used, and a count taken before and after interposition of a filter. For γ-rays, if reasonable sensitivity is required, a scintillation counter may be necessary, with a heavy filter used to absorb the β-rays. If both isotopes emit γ-rays of different energy, the dependence of pulse size on energy can be used (*11*).

For most biological investigations, for reasons of convenience and simplicity, the preferable instrument is the G-M counter.

General Treatment

For a mixture of two isotopes, a count is taken before and after some operation, which may be passage of time, transfer of the specimen from one detection apparatus to another, interposition of a filter between sample and counter, or change in discriminator bias of a scintillation counter.

If N_1 is the first, or unmodified, count; N_2 is the second, or modified count; I_1 is the contribution to N_1 of isotope 1; and I_2 is the contribution to N_1 of isotope 2; then

$$N_1 = I_1 + I_2 \qquad (1)$$

$$N_2 = mI_1 + nI_2 \qquad (2)$$

where m and n are the relative efficiencies of the two systems for each isotope. For isotope 1 alone, $m = r$, and for isotope 2 alone, $n = r$, where $r = N_2/N_1$. Thus

$$I_1 = N_1 \frac{r - n}{m - n} \qquad (3)$$

$$I_2 = N_1 \frac{r - m}{n - m} \qquad (4)$$

$$\frac{I_2}{I_1} = \frac{m - r}{r - n} = S \qquad (5)$$

These equations give a convenient method of determining the contribution of each isotope. Although alternative procedures are possible, this approach leads to a simple practical method for calculating S from r since a calibration graph can generally be constructed.

Errors

The apparatus must be designed to minimize errors, and for this purpose it is necessary to investigate the effect on the final result of an error in each of the contributory measurements (*12*).

If $\Delta\eta$ is the standard deviation of η, then

$$\left(\frac{\Delta I_2}{I_2}\right)^2 = \left(\frac{\Delta N_1}{N_1}\right)^2 + \frac{(\Delta m)^2 + (\Delta r)^2}{(r - m)^2} + \frac{(\Delta m)^2 + (\Delta n)^2}{(n - m)^2} \qquad (6)$$

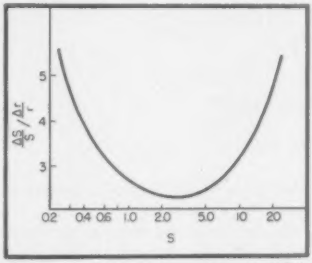

FIG. 1. Variation in error of the Na^{24}/K^{42} ratio for the case $n = 0.0522$, $m = 0.369$

Since m and n can be determined at leisure, the third term on the right can be made negligible. Hence

$$\frac{(\Delta I_2/I_2)^2}{(\Delta r/r)^2} = \left(\frac{r}{\Delta r}\right)^2 \left[\left(\frac{\Delta N_1}{N_1}\right)^2 + \frac{(\Delta m)^2 + (\Delta r)^2}{(r - m)^2}\right] = \left(\frac{r}{\Delta r}\frac{\Delta N_1}{N_1}\right)^2 + \frac{r^2[(\Delta m/\Delta r)^2 + 1]}{(r - m)^2} \qquad (7)$$

Since $\Delta m/\Delta r \ll 1$, and since $r = (m + nS)/(1 + S)$, then

$$\frac{(\Delta I_2/I_2)^2}{(\Delta r/r)^2} = \left(\frac{r}{\Delta r}\frac{\Delta N_1}{N_1}\right)^2 + \left[\frac{m + nS}{(n - m)S}\right]^2 \qquad (8)$$

Similarly

$$\frac{(\Delta I_1/I_1)^2}{(\Delta r/r)^2} = \left(\frac{r}{\Delta r}\frac{\Delta N_1}{N_1}\right)^2 + \left(\frac{m + nS}{m - n}\right)^2 \qquad (9)$$

and

$$\frac{(\Delta S/S)^2}{(\Delta r/r)^2} = \frac{1 + S^2}{S^2}\left(\frac{m + nS}{m - n}\right)^2 \qquad (10)$$

Since $\Delta r/r$, the relative error in r, can be made constant for counts of equal statistical accuracy, the left-hand term is, in each case, proportional to the relative error of the estimation of the desired quantity. The greater the proportion of one isotope, the smaller is its error of estimation.

It has already been shown that S may be of great biological importance. Its value is determined most accurately for intermediate values. But for both very large and very small values of this ratio the determination is very inaccurate, as can be seen from Fig. 1, which has been drawn for the particular arrangement used by the authors where $m = 0.369$ and $n = 0.0522$. The choice of isotope ratio should be governed by the above equations.

Now let

$$E = \frac{\Delta S/S}{\Delta r/r} \text{ or } \frac{\Delta I_1/I_1}{\Delta r/r} \text{ or } \frac{\Delta I_2/I_2}{\Delta r/r} \qquad (11)$$

and let the factor by means of which the initial count is modified, filter thickness for instance, be x. Then the variation of error with the operation of this change in physical conditions will be $\partial E/\partial x$. The relative error is proportional to E and should, therefore, be a minimum when $\partial E/\partial x = 0$ and $\partial^2 E/\partial x^2$ is negative.

There are two cases to consider. The first is when $\Delta r/r$ is independent of x. This applies when all readings and counts are made to the same statistical accuracy. For all the above equations, then

$$m\frac{\partial n}{\partial x} = n\frac{\partial m}{\partial x} \qquad (12)$$

In the second case, $\Delta r/r$ is not independent of x. Then, if the time taken to count N_1 is K, and that taken to count N_2 is kK

$$\left(\frac{\Delta r}{r}\right)^2 = \frac{1}{N_1 K}\left[\frac{km + (kn + 1)S + 1}{k(m + nS)}\right] \qquad (13)$$

and so, for example

$$\left(\frac{\Delta S}{S}\right)^2 = \frac{1 + S^2}{kKS^2N_1} \times \left[\left\{\frac{km + (kn + 1)S + 1}{(m - n)^2}\right\}\{m + nS\}\right] \qquad (14)$$

where a minimum value of $\Delta S/S$ is

desired. Similar expressions hold for $\Delta I_1/I_1$ and $\Delta I_2/I_2$. For a minimum

$$(\partial m/\partial x)\,[2kn^2S + 2kmn + m + n(2S+1)] = (\partial n/\partial x)\,[2km^2 + 2nmkS + m(S+2) + nS] \quad (15)$$

In the simple case when $S \approx 1$, and $k \gg 1$, this equation simplifies to the first case.

When $S \approx 1$, and $k < 1$

$$\frac{\partial m}{\partial x}(m+3n) = \frac{\partial n}{\partial x}(3m+n) \quad (16)$$

This treatment assumes that the counting rates are all greatly above the background rate and that the readings have been corrected for background but not for resolution losses.

Optimum Conditions

For each of the particular methods that may be chosen, optimum conditions can be found.

Different decay rates. For a pair of isotopes whose decay rates are different

$$m = 2^{-t/\tau_1} \quad (17)$$

$$n = 2^{-t/\tau_2} \quad (18)$$

where t is the time interval between counts, and τ_1 and τ_2 are the respective half-lives. Then

$$\frac{\partial m}{\partial t}\Big/\frac{\partial n}{\partial t} = \frac{m}{n}\frac{\tau_2}{\tau_1} \quad (19)$$

and

$$n = m^{\tau_2/\tau_1} \quad (20)$$

These values are then substituted in Eq. 15.

Davies has used the difference in decay rates of K^{42} and Br^{80} to assay mixtures of these isotopes (*8*). In this case, $\tau_1 = 12.4$ hr, and $\tau_2 = 4.4$ hr. Thus $n \approx m^3$, and $(\partial m/\partial t)/(\partial n/\partial t) = m/3n = 1/3m^2$. If $S \approx 1$ and $k = 10$, which is about the largest convenient value, then, substituting in Eq. 15

$$40m^5 + 3m^4 + 40m^3 + 6m^2 - 1 = 0 \quad (21)$$

Thus $m \approx 0.25$ is the significant value, and the optimum time interval between counts is about 25 hr.

Isotope Characteristics

	Na^{24}	K^{42}
γ-energy (Mev)	1.4 2.8	1.51
β-energy (Mev)	1.4	3.58 (75%) 2.07 (25%)
β-ray half-value thickness (mg/cm²)	85	260
Half-life (hr)	14.9	12.4
Specific activity (mc/gm)	128	10.8

Different radiations. When the emitted radiations are different, $m/n = 0$ or ∞, and this is, therefore, the method of choice. Radiations with different energies may be made to give such m/n values by the choice of particular methods of detection.

Thus, isotopes which emit γ-rays greater than 2.25 Mev may be detected by a neutron counter after the photodisintegration of deuterium. Isotopes which emit γ-rays lower than 2.25 Mev cannot be detected by this method, and hence for mixtures of the two types of isotopes, $m/n \approx \infty$ or 0.

Although such methods may be preferable for physical problems, the low efficiency of detection, apart from considerations of convenience and expense, would probably rule them out for biological investigations.

Different radiation energies. Assay of a mixture of two pure β-ray emitters is best carried out by detecting the β-rays with a G-M counter before and after interposition of an absorber. If the β-ray energies differ greatly, then those from one of the isotopes will be completely absorbed by a certain thickness of filter, and m/n will be ∞ or 0 as described above.

For the more general case, when the β-ray energies are comparable, and if the absorption curve is exponential in the practical range of filter thicknesses, the treatment for obtaining optimum working conditions will be as described for different decay rates.

For isotope mixtures that emit both β- and γ-rays

$$m = m_\beta + m_\gamma \quad (22)$$

$$n = n_\beta + n_\gamma \quad (23)$$

where m_γ is the ratio of counts due to γ-rays alone, obtained before and after interposition of a filter for one isotope, and m_β is the ratio due to β-rays alone, for the same isotope.

For the most common radiations, n_γ and m_γ will be constants for the practical range of filter thicknesses. For such a mixture, Eqs. 22 and 23 become

$$m = e^{-(\ln 2)(\epsilon t_{af}/\tau_1)} + C_1 = 2^{-\epsilon t_{af}/\tau_1} + C_1 \quad (24)$$

$$n = 2^{-\epsilon t_{af}/\tau_2} + C_2 \quad (25)$$

where t_{af} is the actual filter thickness times a factor, ϵ, which depends on the

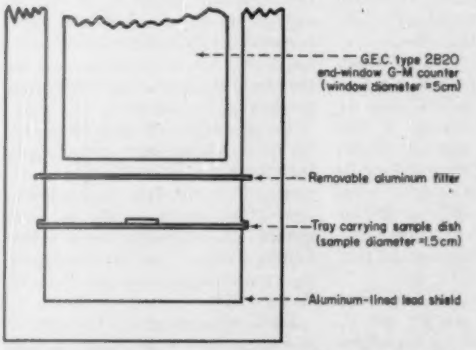

FIG. 2. Arrangement of counter, filter, sample dish, and shield

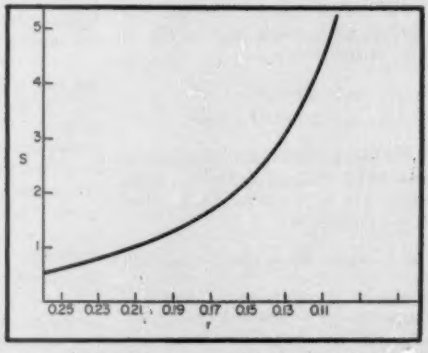

FIG. 3. Calibration curve; $n = 0.0522$, $m = 0.369$

geometrical arrangement; and T_1 and T_2 are the half-value layers for the β-rays of the two isotopes. Then, for optimum conditions when $S \approx 1 \approx k$

$$(m + 3n)\frac{\partial m}{\partial t} = (3m + n)\frac{\partial n}{\partial t} \quad (26)$$

$$[2^{-t_{\text{eff}}/T_1} + C_1 + 3(2^{-t_{\text{eff}}/T_2} + C_2)\{(1/T_1)2^{-t_{\text{eff}}/T_1} = \{3(2^{-t_{\text{eff}}/T_1} + C_1) + 2^{-t_{\text{eff}}/T_2} + C_2\}(1/T_2)2^{-t_{\text{eff}}/T_2} \quad (27)$$

Assay of Na^{24} and K^{42}

A mixture of Na^{24} and K^{42}, which is of biological interest (*13–15*), affords an example of the method. Characteristics of these two isotopes are given in the table.

A β-ray G-M counter is the most convenient detector. The high-energy γ-rays of Na^{24} make a significant contribution to the counting rate, and have the effect of making m/n tend to unity. For this reason, specimens in which self-absorption of β-rays is great, such as samples in solution, are not suitable for assay. The γ-ray contribution could be estimated by interposition of a very thick filter, but such a correction is uncertain and the process is uneconomical of counting time.

The sample was evaporated on a flat dish before counting under a G.E.C. duralumin-windowed β-ray counter as shown in Fig. 2. A count was taken before and after interposition of a filter. After the usual corrections, including subtraction of the constant background from each of the counts, r was calculated. From Eq. 5, a calibration graph of S vs r was drawn (Fig. 3). If the Na^{24} or K^{42} contribution is required separately, the appropriate function of r (Eqs. 3 and 4) is multiplied by the initial counting rate.

For such a mixture, with the geometrical arrangement show in Fig. 2, Eqs. 24 and 25 become

$$m = 2^{-t_{\text{eff}}/T_K}$$

$$n = 2^{-t_{\text{eff}}/T_{Na}} + 0.03$$

For this geometrical arrangement it was found that $T_K \approx 4.34T_{Na}$; from which $n = m^{4.34} + 0.03$. Now, when $S \approx 1$ and $k \approx 1$

$$(m + 3n)(\partial m/\partial t) \approx (3m + n)(\partial n/\partial t)$$

Then, for minimum error, $10m^{4.34} + 0.39m^{3.34} - m - 0.09 = 0$, from Eq. 16, and $m = 0.51$. If $k \gg 1$, and $S \approx 1$, Eq. 12 applies when $m = 0.34$. In practice, $k \approx 5$, and $0.34 < m < 0.51$.

This optimum condition is achieved, in this particular case, by a filter thickness of about 300 mg/cm², which gives an effective thickness of about 400 mg/cm² in the geometrical arrangement shown in Fig. 2.

Finite Sample Thickness

The importance of self-absorption and self-scatter in the assay of β-emitters has frequently been stressed (*16–19*). Recently, Nervik and Stevenson (*20*) have shown that for sample thicknesses in the range below 20 mg/cm², self-scatter may predominate over self-absorption.

In addition to these effects, the influence of backscatter from the material of the sample dish and holder has to be estimated for each assay arrangement (*21, 22*). The absorption of this backscattered radiation in the sample itself considerably modifies the results of pure self-scatter and self-absorption.

In the present investigation, duralumin sample dishes were used. A series of pure Na^{24} sources of identical activity were made up to different thicknesses with a suspension of kaolin in 50% alcohol as spreading agent. These were evaporated to dryness and counted as outlined above.

A second series of K^{42} sources was similarly prepared and counted. The net counting rate of each specimen, after applying the usual corrections, was expressed as a percentage of that obtained with a sample of zero thickness. The results are shown in Fig. 4.

Because of the different radiation characteristics of Na^{24} and K^{42}, m and n are different functions of sample thickness (Fig. 4). It follows that I_1 and I_2 will be functions not only of sample thickness but also of the ratio, S, of the two isotopes present (Fig. 5).

The value of S obtained from the calibration curve based on $S = (m - r)/(r - n)$ is correct only for samples of zero thickness. If this calibration curve is used for thicker samples, the resulting value of S should be modified to $S' = (m - r')/(r' - n)$, where r' is the observed value of r for samples of appreciable thickness. The modification of the true value of S thus introduced is shown in Fig. 5.

In any given case, the important measured quantities are N_1' and r'. Corrections are applied by the following procedure:

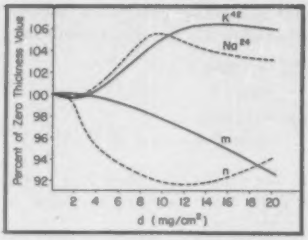

FIG. 4. Influence of sample thickness on counting rate from pure Na^{24} and K^{42} samples, and on values of m and n

1. From a family of curves of r'/r vs r', plotted for the particular geometrical arrangement and range of sample thickness in use, the factor giving the corresponding value of r is obtained.

2. This value is used to obtain S from the standard curve of r vs S; this procedure requires only the one calibration curve.

3. With the S-value so obtained, the appropriate curve of N_1'/N_1 vs sample thickness is selected, and the factor giving the true value of N_1 is obtained.

4. The corrected values of I_1 and I_2 are estimated by using the results of 1 and 3.

It is apparent from Fig. 5 that a sample thickness of 10–12 mg/cm² is most satisfactory, and gives the least variation of estimated S-value for variations in sample thickness.

Geometrical Variation

Putman and Boxall and others have shown that an isocount surface for a single isotope counted by means of a bell-jar β-ray counter is concave towards the counter window (*23, 24*). This is, in the present treatment, an iso-N_1 surface. In the mixed isotope method, using an interposed filter, movement of the specimen towards the counter window, or laterally away from the axis of the counter, will result in a greater effective filter thickness (*17, 25*).

The geometrical efficiency for N_1 and N_2 will vary in the same proportion, so that the value of N_1/N_2 will depend solely on this variation of filter thickness. Thus, an iso-N_1/N_2, or iso-r, surface will be convex towards the counter window. We have confirmed this experimentally for mixtures of Na^{24} and K^{42}.

For a given specimen, S is a function of r only, and the iso-S surface will, therefore, be convex towards the

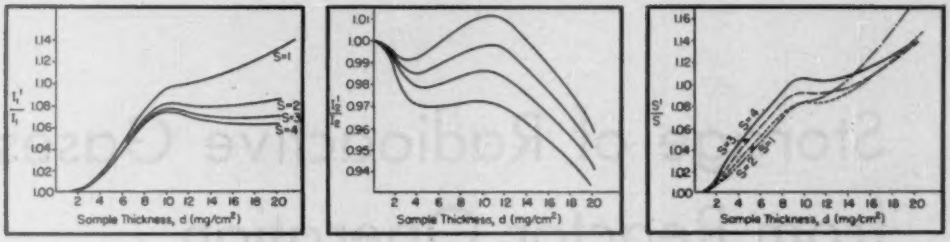

FIG. 5. Influence of sample thickness on estimated values of I_1, I_2, and S. Prime mark indicates quantity has been modified by sample thickness

counter window. Determinations of single-isotope contributions are combinations of functions of r and N_1 so that the iso-I_1 surface in this case will be approximately plane.

To minimize the effects of nonuniform deposition of the solid specimen, the shape of the deposited surface should be "iso" for the particular function to be measured. This means that the surface should be convex or plane, depending on whether the ratio or the individual contributions of the isotopes are required. If both quantities are of equal importance, a specimen tray of small diameter should be used.

Radioactive Impurities

It is both an advantage and a disadvantage of the mixed-isotope method that it is particularly sensitive to the effects of radioactive impurities. If the impurity is known, and its radioactive characteristics differ from those of the other isotopes, corrections can be made, and even additional information obtained from the experiment. But if the presence of the contaminant is unsuspected, large errors may occur.

In biological investigations, such errors may be enhanced by selective tissue uptake. Such errors occurred in the early work on K^{42} metabolism (*26, 27*). Contamination of the K^{42} by Na^{24}, which is preferentially produced in the reactor, is further increased in the extracellular compartments of the living organism. These errors could have been avoided if all samples had been regarded as mixtures of Na^{24} and K^{42}, and treated by the mixed-isotope method.

A common source of radioactive impurity is the initial contamination of the irradiated sample with chlorine atoms. This gives rise, after neutron irradiation, to the presence of S^{35} and P^{32}, so that m and n for the mixed-isotope technique may vary with time.

For mixtures of Na^{24} and K^{42}, the effect of the S^{35} can be eliminated by use of a comparatively thick G-M counter window (about 20 mg/cm²), but the P^{32} β-rays, being of similar energy to those of Na^{24}, may lead to errors if the impurity is not eliminated.

The percentage of P^{32} present is not only a function of the amount of Cl^{35} originally in the target material. Since the $Cl^{35}(n, \alpha)P^{32}$ cross section varies widely with neutron energy, the P^{32} impurity produced in a given time will depend on the energy spectrum of the neutron flux at the point where the Na^{24} and K^{42} are being produced. This source of error can generally be avoided if the bicarbonate salt is irradiated, and the product used for about one week only.

If the radioactive impurities are great, it may be better to sacrifice sensitivity and use a double-filter technique as described by Lewis (*28*).

Future Possibilities

The extension of these methods to *in situ* γ-ray investigations would have great advantages for biological studies of such phenomena as membrane permeability. The physical technique for such an application is now available in the γ-ray scintillation spectrometer. It would seem to be useful to employ this tool in such biophysical investigations.

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Storage of Radioactive Gases from Reactor Operation

A mathematical analysis is presented of the discharge of gaseous fission products in intermittent reactor operations. Storage systems considered are a single long pipe, a single vessel of large capacity, and a sequence of vessels

By RAYMOND L. MURRAY
Physics Department, North Carolina State College of Agriculture and Engineering
University of North Carolina, Raleigh, N. C.

THE MOST hazardous fission products from a homogeneous-type nuclear reactor are the noble gases. In particular, the isotope Xe^{133} is of importance because of its relatively long half life (5.3 days), its chemical inertness, and its large yield (4.5%). This article describes a mathematical analysis of the possibility of continuously discharging such a product through a suitable holding system under conditions of intermittent reactor operation.

Storage-System Analysis

The analysis is based on a combination of radioactive decay and chemical "salt-solution" equations.

Let the number of radioactive atoms per unit volume in the supply to a container, such as one of those shown in Fig. 1, be designated as C_0, and the concentration in the vessel (and the discharge) as C. The net rate of change of C is

$$dC/dt = -\lambda C + fC_0 - fC \qquad (1)$$

where f is the ratio of volume flow-rate to the container volume V_1. The three terms on the right side of the equation are respectively the radioactive decay rate, the rate of influx of new material, and the rate of efflux of old material. During a period in which the flow is stopped, the applicable equation is simply

$$dC/dt = -\lambda C \qquad (2)$$

If, instead, the system were supplied with uncontaminated gas, the equation would reduce to

$$dC/dt = -\lambda C - fC \qquad (3)$$

Single vessel. The solution of Eq. 1 for a single vessel and continuous operation is

$$C = C_0(f/\gamma)(1 - e^{-\gamma t})$$

where $\gamma = \lambda + f$ is the effective decay constant. At equilibrium, the concentration is a fraction f/γ times the supply value.

Series of vessels. In a sequence of n vessels of volume V_1, as shown in Fig. 1, it is clear that the attenuation will be

$$\frac{C_n}{C_0} = \left(\frac{f}{\gamma}\right)^n = \left(\frac{f}{\lambda + f}\right)^n = \left(1 + \frac{\lambda}{f}\right)^{-n}$$

In terms of the volume rate of flow v, and the total volume of the system $V = nV_1$, this reduces to

$$\frac{C_n}{C_0} = \left(1 + \frac{\lambda V}{vn}\right)^{-n} \qquad (4)$$

This relation is applicable of course to a single container, for which $n = 1$.

Single tube. The limiting case of an infinite sequence of tanks of infinitesimal volume is a long tube. By definition of the logarithm base e

$$\frac{C_n}{C_0} = \lim_{n \to \infty} \left(1 + \frac{\lambda V}{vn}\right)^{-n} = \exp\left(\frac{-\lambda V}{v}\right) = \left(\frac{1}{2}\right)^{V/vt_h}$$

This checks with the analysis of a single pipe on the basis of average transit time.

If "slug flow" is assumed, with each atom maintaining its position along the line of motion, the time for a given sample to traverse the pipe is $t = L/u$ where L is the length, and u the velocity. However, if the pipe cross-section is A, then $uA = v$, or $t = V/v$, which is independent of shape. The factor of radioactive decay is then

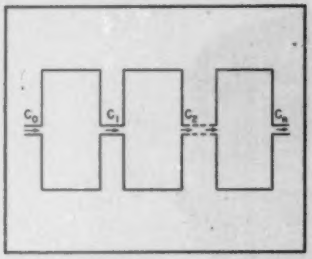


FIG. 1. Sequence of holding tanks supplied with radioactive gas of concentration C_0

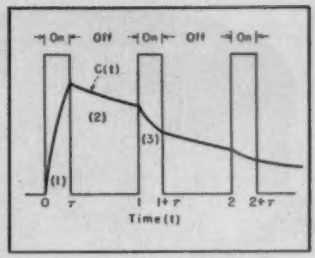


FIG. 2. Concentration as a function of time for single reactor operation cycle

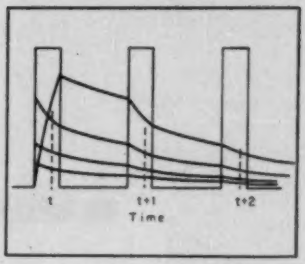


FIG. 3. Superposition of many reactor operation cycles

$(\frac{1}{2})^{t/t_H}$ as found before. If there is complete mixing at all times, the simple transit-time analysis cannot be applied (even though the average time a particle remains in the system is still V/v), and one must return to the solution given by Eq. 4.

Intermittent Operation

If the supply and exhaust is intermittent (on for a time τ and off for a time $1-\tau$) corresponding to the reactor operation, the solutions of Eqs. 1, 2, and 3 must be obtained for the appropriate time intervals. Consider the growth in concentration during the time τ and its decay and discharge during subsequent periods of operation (on) and shut-down (off), as shown qualitatively in Fig. 2. The concentration level in the system, after many cycles of operation, will be the sum of contributions of all preceding operation periods. Figure 3 shows the individual decay curves that must be summed. At a time t during any operating cycle, it can be seen that the sum of amplitudes of the curves is the same as the sum of concentrations $C(t) + C(t+1) + C(t+2) + \cdots$ which may be written as a series

$$C_\infty(t) = C(t) + C(\tau)e^{-\gamma t}e^{-\lambda(1-\tau)} \times \sum_{j=0}^{\infty} [e^{-(\lambda+f\gamma)}]^j$$

Letting $e^{-(\lambda+f\gamma)}$ be represented by x, and making use of the geometric series $1 + x + x^2 + x^3 + \cdots = 1/(1-x)$ for $x < 1$, this reduces to $C_\infty(t) = C(t) + C(\tau)Be^{-\gamma t}$, where

$$B = \frac{e^{-\lambda(1-\tau)}}{1 - e^{-(\lambda+f\gamma)}}$$

The problem of attenuation in a sequence of storage containers may be solved by extending the integration process, in analogy to the radioactive chain problem. The supply to the nth tank will be $C_{\infty,n-1}(t)$ during the operating period. Thus the equation to be solved is

$$dC_n/dt = -\lambda C_n + fC_{\infty,n-1}(t) - fC_n$$

the solution of which is

$$C_n = fe^{-\gamma t}\int_0^t e^{\gamma t}C_{\infty,n-1}(t)\,dt$$

where

$$C_{\infty,n-1}(t) = C_{n-1}(t) + C_{n-1}(\tau)Be^{-\gamma t}$$

It is convenient to introduce the function $F_n = e^{\gamma t}C_n$. Substitution and integration leads to

$$F_n(t) = f\int_0^t F_{n-1}(t)\,dt + Be^{-\gamma t}F_{n-1}(\tau)\,ft$$

Let I be the integral operator $f\int_0^t dt$, and write $Be^{-\gamma\tau} \equiv A$. The value of F_n at time τ, when the concentration is a maximum, is thus

$$F_n = (I + AI\cdot)F_{n-1}$$

where $I\cdot$ implies operation on unity to yield $f\tau$, while I implies integration of a function. From this recursion relation and the condition $F_1 = IF_0$, we obtain the general modified concentration

$$F_n = (I + AI\cdot)^{n-1}IF_0$$

It may easily be shown that $I^2F_0 = (f/\gamma)^2C_0(1-\mathcal{E}_2)e^{\gamma\tau}$ where $\mathcal{E}_2$ is an operator that yields the first k terms of the Maclaurin expansion. Also, $I^{j\cdot} = (f\tau)^j/j!$.

Sample Calculation

As an illustration of the method, we may apply it to a series of three 100-gallon holding tanks, the first of which is supplied with Xe^{133} at concentration C_0 at a rate of 144 liters per day at ¼-day intervals. The system is closed down for the remaining ¾ day.

Now $\lambda = 0.131$ day^{-1}; $f = v/V_1 = 144/378.5 = 0.381$; $e^{-\gamma\tau} = 0.880$; $B = 4.49$; $A = 3.95$; and

$$F_3 = (I + AI\cdot)^2 IF_0 = I^3F_0 + AI^2\cdot IF_0 + AI\cdot I^2F_0 + A^2I\cdot I\cdot IF_0$$

On substituting values of the integrals, and converting back to concentration and simplifying, we have for the maximum

$$\frac{C_3}{C_0} = \left(\frac{f}{\gamma}\right)^3\left[(1 - e^{-\gamma\tau}\mathcal{E}_3e^{\gamma\tau}) + \frac{(\gamma\tau)^2}{2}A(1 - e^{-\gamma\tau}\mathcal{E}_1e^{\gamma\tau}) + \gamma\tau A(1 - e^{-\gamma\tau}\mathcal{E}_2e^{\gamma\tau}) + (\gamma\tau)^2A^2(1 - e^{-\gamma\tau}\mathcal{E}_1e^{\gamma\tau})\right]$$

The necessary expansion of $e^{\gamma\tau}$ is $1 + \gamma\tau + \frac{(\gamma\tau)^2}{2!} = 1 + 0.12775 + 0.00816$. Thus $\mathcal{E}_1e^{\gamma\tau} = 1.00000$, $\mathcal{E}_2e^{\gamma\tau} = 1.12775$, and $\mathcal{E}_3e^{\gamma\tau} = 1.13591$. Substituting numerical values, we obtain $C_3/C_0 = 0.0159$. The concentration ratio due to many previous cycles is computed by multiplying by the fraction $1 + Be^{-\gamma\tau} = 1/(1 - e^{-\lambda-f\gamma}) = 4.95$; the final result is $C_{\infty 3}/C_0 = 0.079$.

A conservative approximation assuming the maximum discharge concentration between tanks is

$$\frac{C_{\infty n}}{C_0} = \left(\frac{f}{\gamma}\right)^n\left(\frac{1 - e^{-\gamma\tau}}{1 - e^{-\lambda-f\gamma}}\right)^n$$

• • •

The assistance of Miss Mozelle Rankin of the Oak Ridge National Laboratory and Mr. J. T. Lynn is gratefully acknowledged.

PALLADIUM foil assembly. Foil is clamped on edge in front of brass shim stock

Use of Palladium-109 as a Multicurie Beta-Ray Source

Commercially available palladium has been used to prepare 1,200-curie sources of pure beta radiation. Relatively inert biologically and having a short half-life, these sources can be safely used for experiments of several hours duration

By W. W. MEINKE,* A. H. EMMONS† and J. V. NEHEMIAS‡
Engineering Research Institute
University of Michigan
Ann Arbor, Michigan

STUDIES of the effects of high-intensity beta radiation on chemical, biological, and physical systems are greatly facilitated by the use of sources which can be easily handled (*1–5*). Although phosphorus-Bakelite plaques (*6*) and Sr^{90} sources (*7*) have been used, other pure beta emitters, such as Pd^{109} are preferred under special conditions.

In a series of experiments (*1, 8*) underway at the University of Michigan, pile-irradiated palladium foils and and chunks of palladium metal providing 7–1,200 curies are being used.

Pd-Source Characteristics

Palladium metal foil, when irradiated in a nuclear reactor, forms 14-hr Pd^{109}, 26-min Pd^{111}, and to a small extent 17-day Pd^{103}. The Pd^{109} and 7.5-day Ag^{111} daughter of Pd^{111} are pure beta-ray emitters except for a small percentage of weak gamma rays recently found in the Ag^{111} decay (*9, 10*). The only additional electromagnetic radiation occurring in high-purity foil several hours after removal from the reactor is the very weak (0.089 Mev) gamma radiation of the 39.2-sec Ag^{109} isomer in equilibrium with the Pd^{109}.

Literature reports (*11*) indicate that 92% of the Pd^{109} decays through the Ag^{109} isomer. About 8% of the Ag^{111} decays by beta-particle emission followed by a 0.34-Mev gamma ray (*9*). In a foil irradiation, this weak gamma radiation is masked by the bremsstrahlung produced by the 0.95-Mev beta particles of the Pd^{109} within the palladium metal. Therefore, the irradiated palladium foil is essentially a pure beta-ray source with self-induced bremsstrahlung.

* Department of Chemistry.
† Radiology Safety Department.
‡ Fission Products Laboratory.

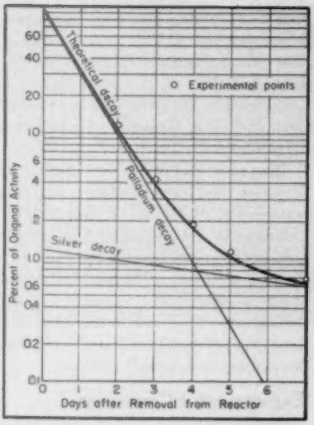


FIG. 1. Decay curve of Pd and Ag activity induced by neutrons in a Pd foil

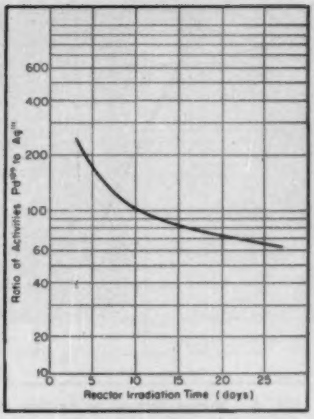


FIG. 2. Ratio of Pd and Ag activities at time of removal from reactor

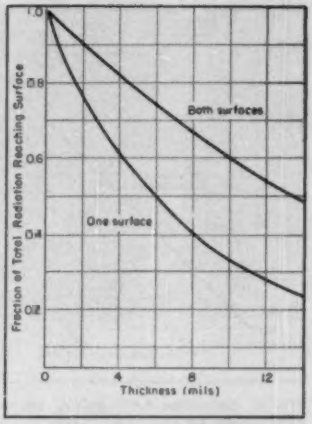


FIG. 3. Fraction of total radiation reaching surface of Pd foil vs foil thickness

Figure 1 shows a beta-particle decay curve of the gross activity on a smear from a palladium foil, with the 14-hr Pd^{109} decaying until the 7.5-day Ag^{111} is dominant. Knowing the thermal-neutron absorption cross section of Pd^{110}, it is possible to estimate the amount of contaminating 7.5-day Ag^{111} that would result from a given reactor irradiation. This calculation assumes the absence, or a minimal effect, of resonance formation of palladium isotopes by more energetic neutrons. The small effect of resonance formation is substantiated by the approximate agreement between the theoretical curve and experimental points. If one is interested only in the 14-hr palladium activity, irradiation time should be limited to a saturation activation of Pd^{109} (about 4 days). Since total irradiation time cannot always be so judiciously selected, it is of interest to evaluate the relative amounts of 14-hr palladium and 7.5-day silver resulting from irradiation of palladium in a reactor. Figure 2 shows this relationship.

Analysis of Pd. High-purity palladium metal is available from a number of suppliers.* Fabrication of special source designs will also be undertaken by these companies. Typical analysis data of high-purity metal from one of the companies is tabulated in Table 1. (Spectrographic analysis was performed by the service laboratories of the Chalk River reactor when nominally 99.9+% pure foil, upon removal from the reactor, appeared to have a higher gamma background than would be expected for pure Pd.) Half-life and radiation characteristics (*12*) of the most prominent isotopes obtained from these contaminants in a reactor are also given in Table 1.

The analysis values are expressed in percentages of palladium present. Of the impurities listed, only the gold would be expected to contribute to contaminant activity in a short-period (one or two week) foil activation. Calculations show that this gold activity would be almost obscured by the Pd^{109} and Ag^{111} of the foil. (The experimental points of Fig. 1 represent the decay of a palladium source from another supplier. This metal apparently contained much less gold.)

Experimental dose limits. There are definite limitations on the activity which a beta emitter can effectively contribute to the radiation dose on a specified experimental system. One familiar limitation is that of self-absorption in the source material. Figure 3 depicts the fractional contribution of beta radiation from one, or both, sides of a palladium foil of a given thickness. The derivation of this graph is given elsewhere (*1*).

A second familiar limitation is the available beta flux per unit mass of matter, i.e., specific activity. The specific activity is dependent upon the neutron flux of the reactor in which the irradiation takes place. Figure 4 shows the saturation activity in curies of Pd^{109} attainable in one gram of palladium metal at different neutron-flux levels. The high-flux positions in various reactors are indicated as current literature values (*13, 14, 15*) and are only approximate. The saturation activity level will be dependent upon the particular reactor utilized, the irradiation position within a given reactor, and the attenuation of the neutron flux by the mass of the source.

It should be pointed out that source sizes can be quite restricted depending upon which reactor is used. The Chalk River reactor can take samples of ¾-in. diameter and 1¾-in. length for insertion into its highest flux position, while the Brookhaven reactor has ports which can handle materials of somewhat larger dimensions for special work. At the present time the Chalk River reactor has the added disadvantage that it must be completely shut down before a sample can be taken out of the high-flux position. A regular shutdown is scheduled only once every week or two weeks. On the other hand, a capsule may be removed from the high-flux position of the Brookhaven reactor at any desired time without shutdown. The Chalk River reactor was selected for most of the experiments discussed here because of the high flux available.

The short (14-hr) half-life of Pd^{109} presents problems for research laboratories located at some distance from a high-flux reactor. Transportation

* American Platinum Works, 1026 Oliver Street, Newark, N. J.; J. Bishop and Co., Platinum Works, Malvern, Pa.; and Baker and Co. Inc., 113 Astor Street, Newark 5, N. J.

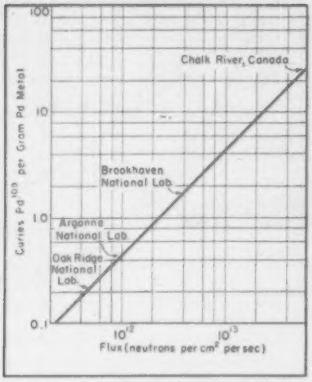


FIG. 4. Saturation Pd^{109} activity attainable at different neutron flux levels

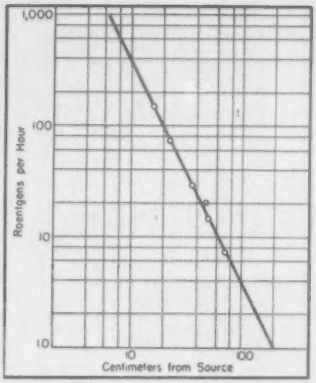


FIG. 5. Dosage rate as a function of distance from a 90-curie Pd foil

TABLE 1—Typical Analysis of "High-Purity" Palladium Metal

Impurity	*Percent present*	*Abundances of parent isotope (%)*	*Cross section ($\times 10^{24}$ cm^2)*	*Isotope*	*Half-life*	*Radiation*
Ag	0.002	51.35	30	108	2.3 min	β
		48.65	2	110	270 d	β, γ
Au	0.1	100	96	198	2.67 d	β, γ
Ca	0.003	2.1	0.6	45	152 d	β
		0.19	0.21	49	8.5 min	β, γ
Cu	0.005	69.1	4.3	64	12.9 hr	β, γ
		30.9	2.1	66	4.3 min	β, γ
Fe	0.02	5.9	0.7	55	4 y	K
		0.33	0.83	59	46 d	β, γ
Mg	0.002	11.3	0.05	27	9.6 min	β, γ
Pt	0.2	0.78	150 (?)	193	4.33 d	β, γ
		25.4	1.1	197	18 hr	β
		7.23	3.9	199	31 min	β
Rh	0.2	100 (10%)	12	104	4.34 min	β, γ
		100 (90%)	137	104	44 sec	β, γ
Si	0.01	3.12	0.12	31	2.7 hr	β

TABLE 2—Activation Data for Palladium Sources

Source	*Dimensions (in.)*	*Weight (gm)*	*Reactor*	*Approx. total curies (Pd^{109})**
1. Pd foil	0.001 × 6¾ × 1¾	1.93	Chalk River	7
2. Pd disk	⅛ × 1¼ dia.	37.5	Brookhaven	75
3. Pd foil	0.001 × 12¾ × 1¾	3.72	Chalk River	30
4. Pd foil	0.005 × 12 × 1¾	19.6	Chalk River	180
5. 7 Pd rods	¼ dia. × 1¾	91	Chalk River	1,200

* At time of arrival at laboratory and beginning of experiment. Time elapsed between end of irradiation and arrival was a minimum of 13 hr from Chalk River and about 5 hr from Brookhaven.

schedules and regulations may preclude the use of this type of source. The short half-life means that the experiments in which such a source is used must be completed rather rapidly and that dose rate must be recorded as a function of time.

The short half-life is an advantage, however, in such matters as contamination of tools. A week or two of decay is the equivalent of a major decontamination procedure.

An additional advantage of palladium is that it is relatively inert biologically (*16*), and hence does not have the inherent health problems that an isotope such as Sr^{90} presents.

Experimental Conditions

Five palladium source activations have been utilized thus far in the series of experiments here. Pertinent data regarding these activations are listed in Table 2.

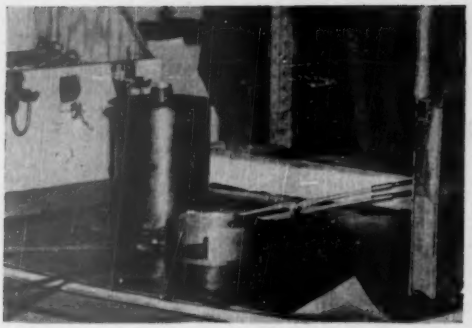
Only a fraction of the Pd^{109} beta radiation present in sources 2 and 5 were used because only the outer 0.013 in. of palladium served as a beta-ray source. Since sources 2 and 5 were inserted into an operating diesel engine to test the effects of beta radiation on the engine efficiency (*1, 8*), thick pieces of palladium were required for mechanical strength and heat conduction in the hot turbulent gas.

The only major complication was caused by an increase in the hardness of the palladium foil within the first day after neutron irradiation. The foil was very difficult to work with and to unroll with tongs. This effect was self-annealed after several days.

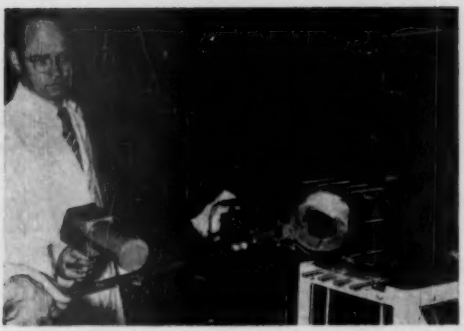
Dosage level. The dosage level in the vicinity of the palladium source is very high, consisting of the primary beta particles and secondary X-radiation (bremsstrahlung).

At a given distance, the observed dosage rate, in rep per hour, varies with the shape and thickness of the source involved. Figure 5 shows a series of measurements made with a radium-calibrated G. E. scintillation gamma probe at various distances from a 90-curie foil of 0.005-in. thickness. Similar measurements were also made with the other palladium sources to indicate dosage rates at distances of several inches.

Shielding. Since 1-in.-thick Lucite sheets furnished insufficient shielding, lead-brick walls were erected with openings at the corners for the insertion



ASSEMBLING palladium foil and brass shim stock



INSTALLATION of source assembly in experimental apparatus

of manipulative tools. These lead walls reduced the radiation level appreciably but introduced discrepancies in monitoring because of the large amount of bremsstrahlung formed.

The shielding was set up beneath a canopy-type exhaust hood. All source handling was done with tongs of various designs—at least 3 ft long. Rather complicated operations, such as unrolling a coiled 12-in.-long 0.005-in.-thick foil, flattening it out, and mounting it in a prepared circular source holder, were accomplished with a minimum of trouble after a number of "cold" practice runs.

Air monitor. A filter-type air monitor, positioned at the edge of the shield area, was operated continuously during each source preparation. The air-activity measurements on the three smaller sources, i.e., 7, 30, and 75 curies, were insignificant. The larger source of 180 curies produced a detectable air-activity level of 5×10^{-8} $\mu c/cm^3$ after extensive manipulation of the foil. Actual personnel exposure to this air contamination was of a lower level since the collector head of the filter unit was positioned directly at the top edge of the shield wall. In view of this detectable air contamination, however, it is recommended that hood or exhaust-air facilities be available when the use of high-level palladium beta-ray sources is contemplated.

Contamination. All equipment that contacted the foil was contaminated with "rub-off" palladium activity. When a piece of equipment entered the "hot" area, it was immediately suspected of contamination and placed, after use, in a can specifically provided for contaminated articles. The contaminated tongs had been found to act as secondary contamination sources, leaving spots of palladium activity on anything they touched. These spots often had activities as high as 25–50 mrep/hr, and could be transferred easily. Any slight carelessness could contaminate an entire laboratory.

The weight of palladium required as "rub-off" from a 20-curie, 2-gm source to produce 1-mrep/hr beta contamination is of the order of 0.04 μg. It is difficult to say, therefore, whether the palladium metal is rubbing off directly or whether the metal surface has become slightly oxidized under neutron bombardment and the oxide is rubbing off. In any event, this large amount of "rub-off" is a definite disadvantage in the use of multicurie Pd^{109} sources.

Personnel exposure. Those involved in the manipulations or experimental applications were provided with personnel monitors of two general types—small pocket chambers and film badges. All film was processed at Oak Ridge. Recommended maximum weekly permissible exposure levels—1.5 rep to the hands, 0.3 rep to the body (*17*)—as measured by the pocket chambers, were never exceeded.

Large discrepancies, however, manifested themselves in the personnel-monitoring data. Dosages as determined by gamma-calibrated film badges were often many fold larger than the same dosages determined by ionization-chamber measurements.

The radiation outside the lead shield was completely due to bremsstrahlung, most of which was in the low X-ray region. At these energies one expects a many-fold increase in the density produced per given amount of dosage incident upon the film (*18*).

The radiation from the foil, with no shielding, was found to be about 85% beta radiation. The Oak Ridge film-processing unit suggests increasing the reported dose threefold in beta-ray measurements, since for a given dose gamma radiation blackens the film to a greater extent than beta radiation.

When one applies these considerations to the monitoring data, the apparent discrepancies resolve themselves, and the apparent overexposures are brought within the range of exposure policy.

* * *

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Activation Assaying for Tantalum Ores

The details on irradiation times, neutron sources, and amounts of sample required are given for this simple application of the radioactivation method for assaying tantalum-bearing ores. A correction is required if, in addition to the tantalum, the ore contains uranium

By G. G. EICHHOLZ
Radioactivity Division
Dept. of Mines and Technical Surveys
Ottawa, Canada

IN RECENT YEARS, increasing use has been found for the metals tantalum and niobium, particularly for high-temperature alloys. As a result, there is renewed interest in various mineral deposits containing these elements. The two elements have close chemical similarity so that it is relatively easy to separate the two together from other elements, but fairly hard to determine the separate content of either tantalum or niobium alone. A simple way to do the latter is by the method of radioactivation, which permits the determination of the tantalum content of any ore and hence also, indirectly, of the niobium content if supplemented by straightforward chemical tests.

The main principle of activation analysis rests on the detection of induced activity from the test sample after it has been exposed to a suitable source of bombarding particles (*1*, *2*). In the present case, only neutron sources are considered, but similar considerations would also apply to proton or gamma-ray sources. Such analysis is feasible if: 1) the element to be assayed is easy to activate with the bombarding source on hand, 2) the activity produced is easy to detect and of sufficient intensity, 3) the activated element has a long enough half-life to be handled and transported easily, and 4) all other elements in the ore have such activation properties as to make it a simple matter to distinguish between them and the assay element. The latter condition is satisfied if all other elements have shorter half-lives or smaller activation cross sections (i.e., activation probabilities) or if they emit weaker radiations.

In view of the large number of elements that may be involved in any mineral, it is only rarely that all these conditions can be met. Fortunately, they can be met in the case of tantalum.

Activation Conditions

Assaying the tantalum content of mixtures by neutron irradiation was first investigated by Long (*3*) who tested various mixtures of tantalum and niobium oxide and showed that no serious interference occurred when small amounts of Sn, Si, Fe, Ti, and Zr were added. He found that self-absorption could be practically eliminated if at least equal amounts of a matrix material such as graphite are present. This condition is normally satisfied in ores.

The activity of any element irradi-

TABLE 1—Typical Analyses of Tantalum-Bearing Minerals

	Columbite-Tantalite		*Rutile*
MnO	14.8%	1.2%	....
FeO	5.5	14.3	8.3%
SnO_2	0.9	0.8	2.7
NbO_5	68.0	13.1	6.9
Ta_2O_5	9.9	70.5	36.0
TiO_2	0.5	....	45.7

	Euxenite		*Fergusonite*	*Formanite*
CaO	2.0%	2.2%	2.60%	2.20%
MgO	0.3	....	0.05	.....
Y_2O_3	22.7	23.0	2.00	23.00
Er_2O_3	14.0	8.4	25.00	8.40
Ce_2O_3	3.3	0.9	1.40	0.90
UO_2	8.2	1.2	3.50	1.20
SnO_2	0.8	....	0.10	.....
Nb_2O_5	43.4	2.2	46.70	2.15
Ta_2O_5	2.1	55.5	2.00	55.50
H_2O	4.2	....	3.20	.....
MnO		0.9		0.90
ThO_2		1.0		1.00
TiO_2		2.2		2.20
FeO			2.00	
La_2O_3			4.00	
Nd_2O_3			4.10	
ZrO_2			2.10	
Traces			BeO, WO_3, Na_2O	

ated in a beam of particles is given by the following equation (*4*, *5*)

$$A = \frac{mN_0}{M} F\sigma(1 - e^{-0.7T/\tau})e^{-0.7t/\tau} \quad (1)$$

where A is activity, i.e., particles emitted per sec; m is mass of bombarded substance in grams; N_0 is Avogadro's number, M is atomic weight of element, F is bombarding flux in n/cm²/sec; σ is activation cross section in cm²; τ is half-life of active nucleus, T is time of irradiation; and t is time elapsed since irradiation.

If T is less than one sixth of the half-life of the product isotope, Eq. 1 can be simplified by the approximation

$$A = 0.7 \frac{mN_0}{M} F\sigma \frac{T}{\tau} e^{-0.69t/\tau} \quad (2)$$

$$= A_0 e^{-0.69t/\tau} \quad (3)$$

where A_0 = initial activity after irradiation.

By comparing the values of A_0 obtained for practical amounts of material and for various times of irradiation, it is possible to estimate the number of counts measured by a suitable radiation detector. Equation 3 may then be used to correct for impurities with different half-lives, if necessary. The activity of any sample is directly proportional to the mass m of the wanted element present. There is, therefore, no theoretical limit to the counting rate attainable as, in theory at least, one simply requires a larger sample of the mineral if the desired element is present in low concentrations only. In practice, the size of sample is limited by detector geometry and bombardment conditions.

The detector should be calibrated by exposing a sample containing a known amount of the element to the flux of the bombarding source and comparing the resultant counting rate with that for an unknown sample exposed under identical conditions. In this case, the mass of the element in the unknown sample is given by

$$m_1 = m_0 (A_1/A_0) \quad (4)$$

where the subscript 0, refers to the standard sample. Before applying this relation care must be taken to correct for any contribution to the counting rate due to various impurity elements present in the ore.

Activation conditions in tantalum minerals. To assess the contribution to the measured induced activity of the various elements found in tantalum ores, a survey was made of the usual composition of such ores. Typical analyses of such ores do not seem to have been made in many cases, and most of the information quoted here is from Dana (*6*) and Ellsworth (*7*).

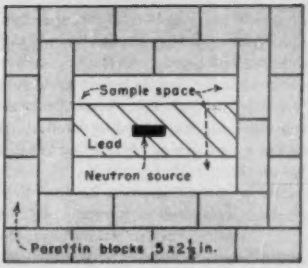

FIG. 1. Paraffin enclosure surrounds radium-beryllium-source for irradiations. Lead shield is used to block gamma rays from Ra:Be, which emits gammas copiously; it is not needed with RaD:Be source

The most important tantalum-bearing minerals in Canada are columbite-tantalite, rutile, fergusonite and formanite, and euxenite. While the composition of these ores fluctuates considerably, the analyses shown in Table 1 were selected to give an idea of the extremes in distribution encountered in such ores. In addition to the elements listed, silicon and carbon can be assumed to occur in various proportions. All the elements listed might be expected to contribute to the final activity of the bombarded sample.

A survey of nuclear data (*8*) shows that all the elements associated with tantalum in these ores have radiation characteristics that make it possible to distinguish tantalum in their presence. Apart from uranium-235, tantalum-181 has the largest slow-neutron capture cross section (21 barns); the nearest is manganese-55 (13 barns). (The problem presented by the presence of uranium and thorium in some of these ores is considered later.)

Also, of all the isotopes to consider in the problem, tantalum-182 is the only one which combines a long half-life with high-energy gamma radiation and a large neutron cross section. Its long half-life makes it possible to let the sample "cool down" for a day or two after irradiation to permit decay of all the short-lived isotopes without appreciable loss in tantalum emission. At the same time, it necessitates a relatively long irradiation, because a long half-life means a low specific activity.

Experimental Procedure

Three neutron sources were available for irradiation experiments.

1. The Chalk River NRX reactor, providing a flux from 10^{12} to 5×10^{13} n/cm²/sec.
2. A 400-mg RaD:Be neutron source emitting 110 mc of radiation.
3. A 500-mg Ra:Be neutron source emitting 500 mc of radiation.

Total flux provided by sources 2 and 3 is about 2 to 7×10^6 n/sec.

Pile irradiations. Several samples of varying size and composition were irradiated in the Chalk River NRX reactor. The size of sample and length

TABLE 2—Experimental Results with RaD-Be and Ra-Be Sources

Target material	Irradiation time	Cooling time	Scintillation counter: Corr. count (cps)	Scintillation counter: Background (cps)	Ionization chamber: Corr. count (*)	Ionization chamber: Background (*)
RaD:Be (400 mg)—						
4.3 gm Ta metal	5 days	4 hr	0.61	1.52	3	150
130 gm K_2TaF_7 (46% Ta)	3 days	4 hr	4.70	1.48	35	150
88 gm TaC powder	17 hr	....	1.79	1.49		
88 gm TaC powder	9.5 days	2 hr	14.6	1.50		
10% Ta synthetic (8 gm)	8.7 days	2 hr	0.87 1.12	1.54 1.55		
Ra:Be (500 mg)—						
80 gm TaC powder	7 days	1 hr	38.2	1.32		
5 gm TaC powder	7 days	1 hr	7.0	1.36		

* Reciprocal charge time values obtained with an electrometer.

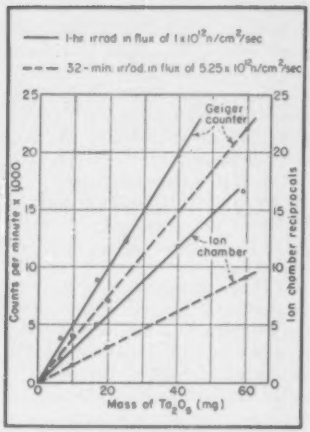
1-hr. irrad. in flux of 1 x 10^12 n/cm^2/sec
32-min. irrad. in flux of 5.25 x 10^12 n/cm^2/sec
Geiger counter
Ion chamber
Counts per minute x 1000
Ion chamber reciprocals
Mass of Ta2O5 (mg)

FIG. 2. Activity plot, Ta_2O_5 samples irradiated in Chalk River NRX reactor

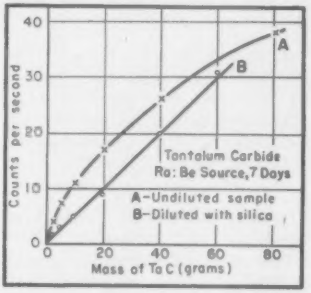

FIG. 3. Effect of self-absorption (curve B was obtained several days later than curve A)

TABLE 3—Comparative Chemical and Activation Assays of Tantalum in Various Ore Samples

	Chemical assay (spectroscopic) (% Ta_2O_5)	*Activation assay* (% Ta_2O_5)
Ilmenite (St. Urbain)	n.d.	0.06
Tantalite (Moose Mine, Yellowknife)	35.0	35.6
Columbite	8.0	8.8
Euxenite (Polycrase, Mattawan)	...	7.7
Euxenite (S. Sherbrooke)	5.3 (also 22.28% Nb_2O_5, 8.7% UO_2)	6.5

of exposure is governed by the flux available and the sensitivity of the detector employed. As the lowest flux obtainable at a service hole in the NRX is 10^{12} n/cm²/sec, a convenient counting rate can be attained by irradiating samples containing 5–100 mg Ta_2O_5 for one hour in that position ($nvt = 3.6 \times 10^{15}$). For 1-gram samples, this would correspond to a range of 0.5–10% Ta_2O_5; larger or smaller sample quantities would cover any range desired because it is only the actual amount of tantalum contained in the sample that matters.

For experimental purposes, work was carried out with 300-mg samples containing 1–80 mg Ta_2O_5, the balance of the weight being made up with powdered silica. In this way, danger from self-shielding effects was eliminated.

Radium-beryllium sources. The flux obtainable with the radium-beryllium sources is rather low, and to keep the irradiation time down to a reasonable value, larger samples must be irradiated.

The sample size is limited on the one hand by the paraffin enclosure usually set up around the source, as shown in Fig. 1, and on the other by the detector assembly. For instance, a scintillation counter arrangement used for uranium assay was designed to handle 80–100-gm samples only. Larger samples can be assayed by a pressure ionization chamber, but the increased size possible is balanced by the loss in detection sensitivity. See Table 2.

Satisfactory results can thus be expected with a week's irradiation for samples weighing 80–200 gm. (Larger samples could probably be handled with a different scintillation counter with liquid or plastic phosphors; in that case, a shorter time would be sufficient for irradiation.)

Experimental Results

Experiments have been carried out mainly with synthetic samples to determine the range and precision of the method, but a few natural samples have also been activated.

With the Chalk River samples where very small samples and short irradiation times were used, the main causes of error are weighing errors and variations in irradiation time. By packing three samples into the same capsule, the latter error is minimized. The solid lines in Fig. 2 show a plot of the results obtained with five synthetic Ta_2O_5 samples irradiated for one hour in a flux of 10^{12} n/cm²/sec. Readings were taken with a pressure ionization chamber and with a Geiger counter with a Victoreen 1B85 tube. In each case, all readings were well above background, indicating that both detectors are satisfactory for this work. This is important in case larger samples have to be handled. The linearity of the graphs indicates that self-absorption was negligible.

Another batch of samples irradiated at Chalk River, this time at a flux of 5.25×10^{12} n/cm²/sec for 32 min, is represented by the dotted lines in Fig. 2. Both counters gave a perfectly linear plot when the samples were measured after a four-day interval. The counting rate was too high to be handled conveniently in our standard scintillation counter setup.

For comparison, Fig. 3 shows the results obtained with some synthetic TaC samples, irradiated by the 500-mg Ra:Be neutron source for 1 week. The sample quantities involved here were very much greater and curve *A* indicates the effect of self-absorption observed with pure TaC powder. Curve *B* shows how this effect is removed by diluting the tantalum carbide with silica. In practice, the tantalum concentration in ores would be relatively low, and no correction for self-absorption would be required.

Table 3 lists the activation determination of tantalum in various small ore samples provided by the Geological Survey of Canada. These samples were irradiated at Chalk River together with a 15-mg Ta_2O_5 calibration sample.

Fission Correction

Although the main tantalum-bearing ores like columbite-tantalite and the titanium ores do not usually contain fissionable elements, it may be desirable on occasion to determine the tantalum contents of euxenites which contain both thorium and uranium in varying proportions. As uranium undergoes fission when bombarded with slow neutrons, there will be a contribution to the final counting rate due to the radiation emitted by the various fission products. If a long enough irradiation time is used, for most tantalum ores this radiation and the neutron-induced tantalum activity will give rise to a counting rate well above that due to natural radioactivity of

uranium in equilibrium with its decay products (mainly radium C, in the case of a gamma detector), so that the latter's contribution may be neglected.

The effective fission cross section of natural uranium is 3.9 barns, one fifth that of tantalum. As a result of fission, a large number of isotopes are produced ranging from $_{30}Zn^{72}$ to $_{64}Gd^{158}$ instead of the single isotope produced by neutron activation. Only a small portion of this range is produced in large enough numbers to be readily detectable. In addition, under the conditions of measurement, only those fission products having a long half-life and emitting a strong gamma ray will be detected. These properties have been tabulated (*9*) and from the list it is simple to pick out the isotopes that matter in this connection. The point to be borne in mind is that many fission-products decay through a chain process, with all members of the chain eventually attaining equilibrium. Two of the more important chains involve the decay of Y^{95} to Mo^{95} and Xe^{140} to Ce^{140}. A member of the latter chain is La^{140}, which will reach equilibrium and emit its 1.6-Mev gamma ray with an effective half-life of 12.8 days. Consequently, the presence of uranium is equivalent to the presence of an element with a long-lived activated isotope emitting 1.6-Mev gamma rays though with a relatively low cross section ($3.9 \times 0.061 = 0.24$ barn). In view of this, a fission correction is required only if a relatively large proportion of uranium is found in the ore, a fact easily ascertained by standard uranium-assay methods.

To check these conclusions, known amounts of U_3O_8 were added to some synthetic Ta_2O_5 samples and irradiated in the Chalk River reactor under the same conditions as the pure Ta_2O_5 samples. The results are plotted in Fig. 4, which shows the counting rate attributable to the fission activity alone. By comparing these readings with those obtained for tantalum alone and shown by the dotted lines in Fig. 2, it was possible to work out the "tantalum equivalent" of uranium in ores, i.e., the apparent quantity of tantalum which would be obtained from a radiation assay under the conditions of flux exposure and cooling-off time employed in this experiment. These results are tabulated in Table 4.

The counting rates listed in Table 4 apply, of course, to the specified conditions only, in view of the several fission products of various half-lives involved. Figure 5 illustrates the effect with a plot of the decay characteristics of two synthetic tantalum oxide samples, together with a typical euxenite sample. All were irradiated and assayed under identical conditions. The graph shows how the shorter-lived fission products decay over the period of a month and the sample gradually approaches the steady decay conditions of its tantalum component.

To overcome this practical handicap, it is more expedient to correlate the fission activity at a given moment with the uranium activity of the unbombarded sample in a given measuring setup. For this purpose, a graph has been plotted which makes it possible to determine directly the "tantalum equivalent" of a given amount of uranium referred to a stated time of tantalum assay. See Fig. 6.

For convenience, the initial counts have been expressed for a Geiger counter and a scintillation counter. The straight-line relationship makes it easy to extrapolate this graph to other values.

No fission correction is required if the irradiation is carried out with a Ra:Be source because of the low saturation activity obtained. In this case, it is sufficient to subtract the pre-irradiation counts from the final counts.

* * *

It is a pleasure to acknowledge the assistance of C. M. McMahon and L. A. Ficko in obtaining many of the assay results reported.

Thanks are also due to the authorities of the National Research Council, Chalk River Laboratories, and Eldorado Mining and Refining (1944), Ltd., for facilitating the pile irradiations, to Dr. H. V. Ellsworth of the Geological Survey of Canada for providing ore samples, to the Sun Tube Corporation of Canada for developing aluminum sample tubes, and to the National Research Council, Ottawa, for the loan of the Ra:Be neutron source.

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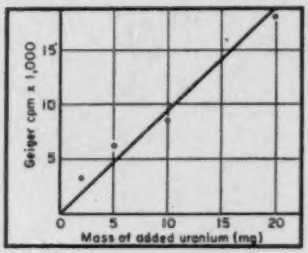

FIG. 4. Contribution to counting rate of uranium fission (after subtraction of Ta_2O_5)

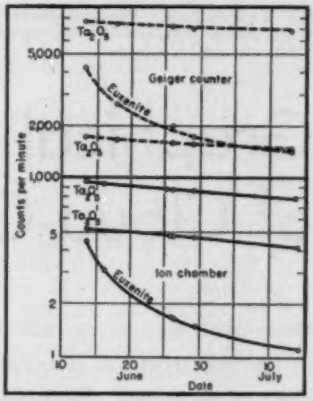

FIG. 5. Decay curves for activated samples. Note change in scale for the two different detectors

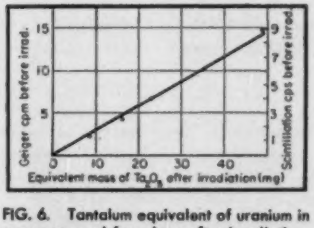

FIG. 6. Tantalum equivalent of uranium in ores measured four days after irradiation

TABLE 4—Contribution of U_3O_8 Activity to Counting Rate (4 Days after Exposure)

U_3O_8 (mg)	*Counts per minute*
2	3,210
5	6,110
10	8,520
20	18,020

NOTE: Pre-irradiation counts = 2–14 cpm

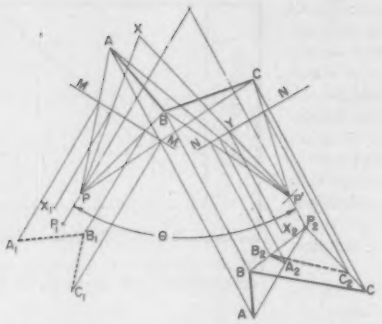

FIG. 1. Orthographic plan and elevation views of particle tracks *ABC* are obtained from two stereoscopic photographs, $A_1B_1C_1$ and $A_2B_2C_2$, of tracks

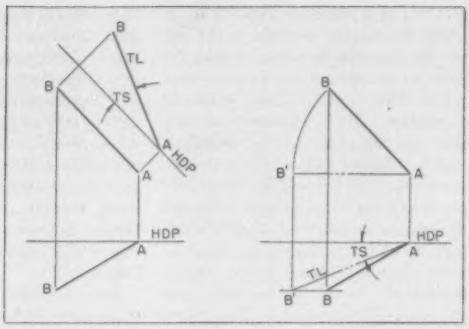

FIG. 2. True length and true slope of particle track is obtained by using new datum plane or by rotating track to be parallel to existing datum plane

Graphical Analysis of Cloud-Chamber Photographs

Descriptive-geometry techniques can provide true lengths and directions of particle tracks in cloud-chamber stereophotographs. Spatial angles and radii of curvature of curved tracks are also quickly and accurately measured

By J. S. CAMPBELL and D. F. WELCH
Department of Engineering Drafting
California Institute of Technology
Pasadena, California

STEREOSCOPIC PHOTOGRAPHS of particle tracks can provide much valuable information in experimental nuclear physics. But to make quantitative measurements, these photographic perspective views must be interpreted as two-dimensional representations of spatial relationships. Under certain conditions this can be done directly, but usually the photographs must be transformed into orthographic drawings.

An exact graphical method for transformation from perspective to orthographic views is derived in this article. Applications of this method to problems encountered in the interpretation of cloud-chamber photographs are illustrated. Typical of such problems are the determination of the lengths and directions of straight lines, the angles between lines in space, and the radii of curvature of the curved tracks produced by charged particles moving in a magnetic field.

An assumption that the perspective views obtained photographically are actually orthographic is sometimes made purely on the basis of convenience. If it is possible to place the cameras at a considerable distance from the cloud chamber, the error caused by this assumption is so slight that it is negligible in relation to track resolution and other factors. In many experimental arrangements, however, this condition cannot be met.

Transformation of Views

The first step in the accurate analysis of cloud-chamber data is the construction of a pair of orthographic views. To do this, we must know the orientations of the two cameras and have information (camera focal lengths and the distance to some identified point in the photographs) from which the scale of the new views can be determined.

In Fig. 1, a *V*-track appears as the dotted lines $A_1B_1C_1$ and $A_2B_2C_2$ in two related stereoscopic photographs. In each photograph the point where the optical axis of the camera lens pierces the film must be determined. This locates the points P_1 and P_2, the projections of the viewpoints P and P' on the photographs. The direction that vertical lines passing through the viewpoints will take in each photograph must also be determined. Finding this direction and the viewpoint locations is facilitated by providing a grid of vertical lines behind the chamber in the original photographic setup.

The construction is started by drawing projection lines through A_1, B_1, C_1, and P_1 parallel to the vertical line through P_1. At some convenient position the image plane MM is drawn. The viewpoint P for the forthcoming plan view is located on the projection from P_1; the distance from P to MM is

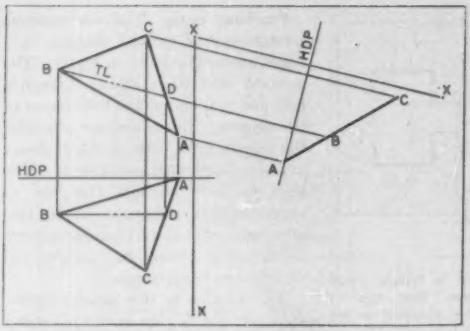

FIG. 3. Edge view of plane is obtained by projecting view parallel to true length line, shows particle X is not coplaner with tracks AB and BC

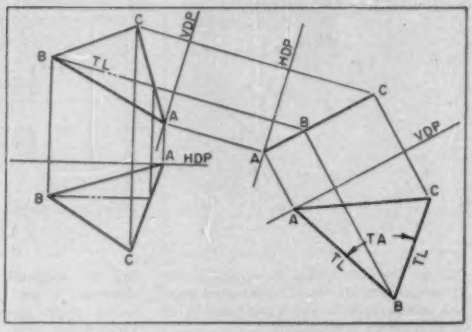

FIG. 4. Projection from edge view of plane containing tracks gives true lengths of tracks AB and BC and the true angle TA between them

the focal length of the camera lens drawn to the scale selected.

Lines are now drawn from P through the intersections of the projection lines with plane MM, and extended beyond this plane into the region in which the plan view will be drawn.

The second photograph, $A_2B_2C_2$, is now placed so that a vertical line passing through point P_2 makes an angle θ with the projection lines of the first view which is equal to the angle between the optical axes of the original cameras. Projection lines are then drawn parallel to this line, and an image plane NN is drawn.

The location of NN in relation to MM must be correct, as it is evident that moving it forward or backward will alter the plan view. When taking the original photographs, the distance from each camera lens to some identifiable point in the picture should be measured. Assume in this case that point X is a suitable fixed point. Then, when the rays are drawn through viewpoint P, the distance PX can be laid off to scale and point X located in the plan view.

In the second view, the distance from the camera lens to point X is also known. This distance is set as a radius on a compass and, using point X in the plan view as a center, we strike an arc which intersects the projection line from P_2, giving viewpoint P'. The projection line from point X_2, already drawn, intersects line $P'X$ at point Y, and here the image plane NN is drawn perpendicular to the projection lines.

Viewpoint P' is thus located at a distance from NN proportional to the focal length of the camera; in most cases matched camera lenses are used for pairs of photographs, and this equals the distance from P to MM.

Rays are now drawn through P' and the intersections of the projection lines with plane NN, and extended until they intersect the corresponding rays from P. These intersections determine the positions of points A, B, and C in an orthographic plan view.

To obtain the related orthographic elevation view, parallel projection lines are drawn from points A, B, and C in the plan view back towards one of the perspective views, in this case the one on the right. Rays are then drawn from point P_2 through A_2, B_2, and C_2 in this perspective view. Where these rays meet the corresponding projection lines, the points A, B, and C are located. These are joined to form the orthographic elevation view.

The two orthographic views so determined give a complete description of the spatial relationships among points A, B, and C, and may be projected to obtain true lengths, angles, etc.

Linear Tracks

Once a true orthographic plan and elevation of a given track are obtained, the true length, TL, and true slope, TS, of this track can be found readily. A track appears in its true length in an orthographic view only when this view is projected on a plane parallel to a plane containing the track. But the true length and true slope of a track randomly situated in space can be found by either of the two simple graphical operations illustrated in Fig. 2. A new datum plane can be established parallel to the track in one of the orthographic views and distances from the datum plane HDP duplicated as at the left in Fig. 2, or the track can effectively be rotated in space until it is parallel to the existing datum plane.

Position of droplets. To determine whether an isolated droplet X is coplaner with a V, an edge view of the plane ABC established by the V is projected, as shown in Fig. 3. To do this, line BD is drawn parallel to HDP in the elevation view; BD in the plan view is now true length, and a view constructed from a datum plane HDP perpendicular to the extension of BD will give an edge view of the plane. If the point or droplet X does not lie along the line representing the edge view of the plane ABC or the line extended, it is not coplaner with the V.

True angles. Once an edge view of the plane formed by the tracks of a V is obtained (Fig. 3), only one other view is required to obtain the true angle, TA, between the tracks. As shown in Fig. 4, a view is projected perpendicular to the edge view of plane ABC. As before, measurements from a datum plane, in this case VDP, establish the points on the projections. The view obtained shows tracks AB and BC in true length as well as the true angle TA between them.

Helical Paths

In the interpretation of cloud-chamber photographs of helical tracks left by charged particles moving in a magnetic field, the problem arises of determining the radius and pitch of the helical path. The solution for this type of problem, although extremely

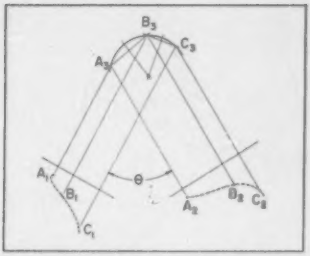

FIG. 5. Simplified case shows how radius of helical particle track is obtained from two orthographic views constructed from cloud-chamber photographs

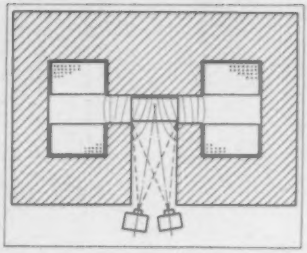

FIG. 6. Magnetic field in typical cloud chamber is not uniform. Thus axis of helical paths cannot be assumed to be vertical

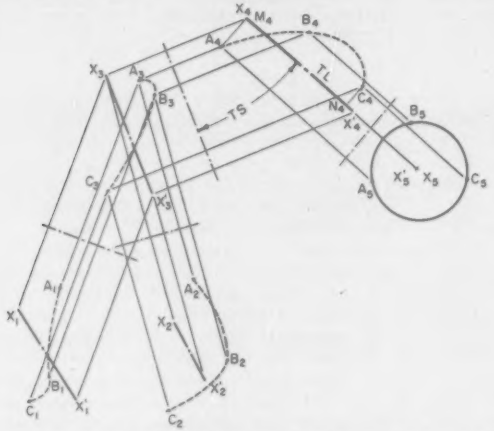

FIG. 7. Actual determination of pitch and radius of helical path made by particle in cloud chamber with nonuniform magnetic field

tedious if done analytically, can be determined simply by graphic means.

Simplified case. First, assume that several points on the helical path have been transformed into true orthographic views or, if the cameras are set up at a considerable distance from the chamber, that the photographs themselves can be regarded as approximate orthographic views.

The next assumption, that of a vertical magnetic field, is a purely academic one for simplification in the first illustration. The conventional magnetic structure about a cloud chamber does not produce this kind of field.

The layout for this overly simplified case is shown in Fig. 5. The photographs or orthographic views are oriented so that vertical lines passing through the center of each picture make an angle θ corresponding to that between the camera axes.

The helix in the photographs is composed of many small droplets, arranged in a sufficiently nonuniform manner so that points on the curve may be located and coordinated between the two photographs. Three such points are located, preferably as far apart as possible, and projection lines are extended into the plan view from both of the two given elevations. The three points, A_3, B_3, and C_3 in the plan are found at the intersections of corresponding projection lines.

Since we have assumed that the magnetic field and therefore the axis of the helix is vertical, the axis will appear as a point in the plan view, and the helix itself will appear as a circle. Three points are sufficient to determine a circle, and so the solution is completed by drawing perpendicular bisectors of the chords A_3B_3 and B_3C_3, and locating the center of the circle at their intersection.

Practical case. The conventional arrangement of a cloud chamber in a magnetic field is shown in Fig. 6. The cameras view the chamber through a hole cut into one of the pole pieces of the magnet. In the absence of a hole, the lines of force through the chamber would be horizontal and parallel. The hole, however, distorts the field as suggested in the figure, so that the flux at certain parts of the chamber departs considerably from its undisturbed direction and magnitude.

The solution in this general case is shown in Fig. 7. As in the preceding example, views *1* and *2* are photographs or orthographic drawings upon which points *A*, *B*, and *C* are identified. The views are properly oriented and three points on the helix are located in a plan. First an arbitrary line X_3X_3' representing the axis of the helix is drawn in a direction parallel to the magnetic lines of flux at a point close to A_3B_3 and C_3 on the basis of a chart of field direction throughout the particular chamber. This may be in the form of an angle with respect to the front windows and a slope.

Next, a true-length view of this line is constructed by drawing projection lines at right angles to the projection of the line in the plan view and locating points A_4, B_4 and C_4, in view *4*. Since this view will show the axis in its true length and a horizontal plane will appear as an edge perpendicular to the projection lines, the proper slope *TS* may now be established. The function of the assumed axis in this view is merely to give us the direction in which to look to see it as a point and thus to see the helix as a circle; therefore, the true axis need not be exactly located in the first step.

Finally, projection lines are drawn parallel to the axis in view *4*, to obtain view *5*. In this view the axis appears as a point and the helix as a circle whose center will be located again at the intersection of the perpendicular bisectors of chords *AB* and *BC*.

The pitch of the helix is the distance advanced along the axis in one complete turn. This is readily obtained from views *4* and *5* of Fig. 7. In view *4* (which shows the axis in its true length) perpendiculars are dropped from A_4 and C_4 to determine a distance *MN*. In view *5*, the angle $A_5B_5C_5$ is measured. Then the pitch of the helix is given by: Pitch = $MN\ 360/\text{Angle}\ ABC$.

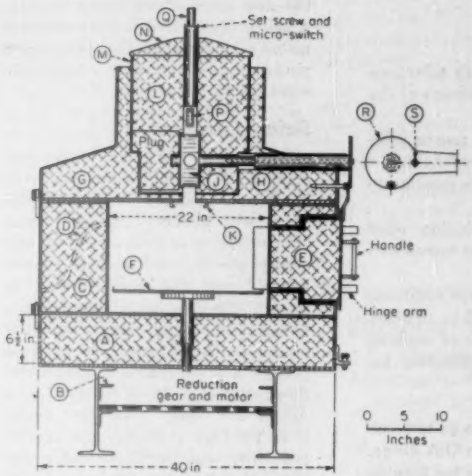

FIG. 1. Access door, mounted on ball bearings, requires levelling of chamber for easy operation. This is done with four adjusting screws on "I"-beam supports

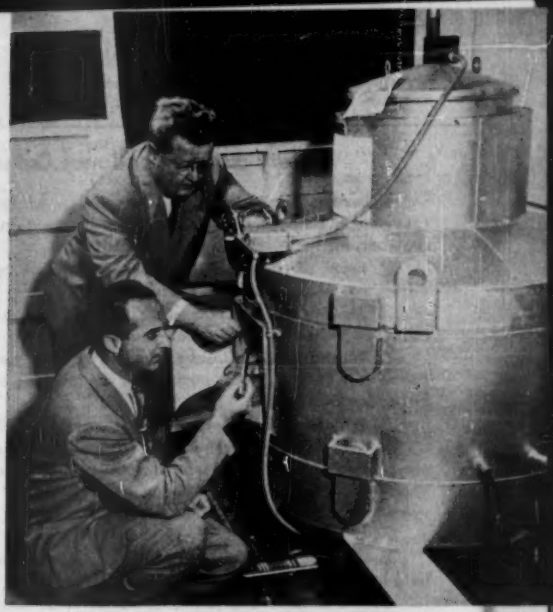

FIG. 2. Lead shielding of chamber is indicated by shaded areas. Four electrical conduits (*D*) for instrumentation leads are welded in place before pouring lead

Cobalt-60 Irradiation Chamber

This lead-shielded 8-ton chamber houses a 100-curie cobalt-60 source. Radiation levels for biological and chemical samples are 30–5,000 r/min; in operation the average reading at the external surface of the chamber is 1 mr/hr

By M. A. GREENFIELD, L. B. SILVERMAN and R. W. DICKINSON
Department of Radiology, School of Medicine and Atomic Energy Project
University of California at Los Angeles, Los Angeles, California

To FIT THE NEEDS of this laboratory, a chamber was designed and built for irradiating chemical or small biological samples with a 100-curie Co^{60} source. Two other chambers (*1*, *2*) had previously been built for multicurie sources.

Our chamber was designed to meet the specifications listed on the following page. It was estimated that the distance from the center of the chamber to the external surface would be approximately 50 cm (radius of working space plus thickness of lead shielding). For a source of 100 curies of Co^{60} at a distance of 50 cm, a thickness of 8¾ in. of lead was selected as being sufficient to reduce the average radiation level to considerably less than whole-body tolerance.

Materials and Construction

Generally, construction is of welded ⅜-in. tank plate and thin-wall steel tubing filled with the necessary lead for shielding. The principal parts of the assembly—the base, body, door, cover, and shipping turret with valve and stem—are shown in Figs. 1 and 2.

Base. The base *A* consists of an open shallow circular tank with a stepped tube in the center. The tank is filled with lead slightly higher than the edges and then sanded or machined level. Reduced shielding in a downward direction is used, but supports *B* are provided to hold supplementary

Safety and Operational Criteria

1. Level of radiation to be at or below whole-body tolerance (assumed to be 6½ mr/hr) at any accessible, external portion of the chamber, independent of source's location.

2. Level of radiation in the working volume, with source withdrawn, not to exceed the tolerance level for hands, 19 mr/hr (*5*).

3. Moving the source from working position to safe position to be accomplished by mechanical means.

4. Mechanical interlocks to prevent opening the main door when source is in the irradiation position, or the lowering of the source with the door open or ajar.

5. Provision for padlock in both operating and storage positions.

6. Working space to be in the form of a cylinder 22 in. in diameter, 12 in. high; source to be approximately in center of working space when being used. This gives 360-degree availability for samples placed on a table that rotates at 2 rpm.

7. Shielding material to be lead.

8. The shipper to be used as part of the chamber so as to eliminate handling of an unshielded source after receipt from Oak Ridge.

9. The shipper and source container to be suitable for loading at Oak Ridge by remote control, under water, and to be self draining to avoid the dripping of contaminated water.

shielding if required for eliminating scatter.

Body. The body *C* consists of an annular open circular tank. The door frame is welded in place between the cylindrical steel walls.

Since it was considered inadvisable to risk having levels of slag and oxides of reduced density (no equipment was available for pouring all the lead at once), thin chevron-shaped spacers were welded between the walls, thus forming eight compartments which could be filled separately. No heavy machine tools were available to serrate the top face, so it was decided to sand the mating faces smooth and use a heavy paste of litharge and glycerine in the joint. (This proved to be inadequate and the remedy is described later.)

Door. The design of the door *E* is critical both as regards operation and shielding. It is built of rectangular section, curved on the vertical sides and stepped top and bottom. The size, 9 × 11 in., is suitable for easy access to the interior; the table *F* is hinged for insertion into the interior.

Cover. The outline of the cover *G* is determined by spotting off a number of points which would give the necessary shielding with the active source in various positions of transit. A tube *H* is provided for operational access to the turret valve *J*, and supports *K* are provided for shielding under the valve. A thin steel cage is welded in place to accommodate the turret so that no fitting is required when the turret is received loaded.

Turret. The turret *L* consists of the outer shell and base with an insert for the rotating valve and a vertical central tube through which the source holder and stem are guided. The disk-shaped valve has a similar tube welded through the body which lines up with the central tube in the turret when in an "open" position and is at right angles to it when in a "closed" position.

Lining up the components of this assembly should be done carefully; otherwise binding may occur during operation and it would be practically impossible to remedy it without remote control equipment for removal of the source. To line up the operating and valve shafts, radial location pins *M* are installed in the turret to register with corresponding slots in the cage.

Supplementary shielding downward is provided for shipping by placing a loose lead plug in the valve hole; this drops out after complete assembly. Extra shielding upward during operation is provided by placing a cap *N* of lead over the top of the turret.

Source holder. The source holder *P* attached to the lower end of the stem *Q* is of aluminum alloy. A jig consisting of a piece of tubing welded to a base plate is supplied for holding the stem upside-down during loading. A hole is drilled close to the bottom to match a hole through the stem, and a pin is inserted to prevent turning when screwing the cap home.

Safety Provisions

Mechanical interlocks to prevent opening the door with the source in irradiation position, or lowering the source with the door open, and means for padlocking in both operating and storage positions are provided by the solenoid and disk mechanism *R* in front of the chamber. The disk (attached to the valve—operating shaft) cannot be turned unless the solenoid plunger *S* is withdrawn by means of a foot switch on a circuit energized by a microswitch only when the source is in the high position. The remote possibility that the source holder becomes detached from the stem is not provided for mechanically. For this reason, it is intended to install a detector in the chamber with an external indicating meter (see p. 74).

Preliminary radiation checks were made with a 300-mc radium source. With well-known tables for the attenuation of the radiation from radium, it was estimated that 8½-in. lead and ¾-in. structural steel would reduce the ionization level of 300 mc of radium to about 0.0056 mr/hr at 50 cm. Flaws were detected by using γ-sensitive film for long exposure times (approximately 100–150 hr). To detect leaks through the shielding material, a G-M type survey meter, a scintillation counter with portable probe, and calibrated photographic films (Eastman type K) were used.

The results of all the methods used were in fair agreement. However, the film-radiographic method not only gave radiation dosage figures which were missed by the survey meters, but also detected flaws and resolved their location. These measurements indicated that the lead had, in cooling, pulled away from the steel container on the top side of the cover bottom plate. The void was filled by pumping a mixture of litharge and linseed oil through an alamite grease fitting.

It was also found that the cover bottom plate had warped to such an extent that the litharge-glycerine mixture originally specified did not completely seal the gap. The cover was jacked up about ⅛ in., the litharge scraped out, and lead wool tamped

hard against a bucking block on the inside of the chamber (the density of such packing was 75 to 90% that of poured lead.)

Another film-radiographic and survey-instrument safety check indicated no radiation above the background level. After the tests were completed, the turret was removed and separately rechecked with the 300-mc radium source. Minor defects were found and corrected. The data obtained with radium in the turret indicated that the expected radiation level with the 100-curie source in the turret would satisfy ICC regulations for transportation of radioactive materials.

When the loaded turret (containing 96.9 curies Co^{60}) was returned from Oak Ridge, it was monitored and the average readings at the side surface of the turret in line with the source were 45 mr/hr. The maximum reading recorded on the top face against the stem guide was 85 mr/hr.

After installing the turret cover, the radiation intensities, given in the table on this page, satisfy the desired safety levels. Loading samples into the chamber or removing them requires only 10–15 sec. It is thought that the basic design of the chamber is suitable for sources as large as 1,000 curies.

Attenuation of Gamma Rays

The distance from the center of the chamber to the external surface is 50 cm. Thus the thickness of shielding material attenuates the radiation of 100 curies of Co^{60} sufficiently to produce levels less than 6¼ mr/hr at 50 cm. Several computations of the absorption of gamma rays by thick layers of lead have been made (*4, 5, 6*).

According to Plesset and Cohen (*6*), the fraction of the gamma-ray energy transmitted through a slab of lead is given by

$$I/I_0 = B(x)e^{-\mu_l(\alpha_0)x}$$

where I_0 is the incident gamma-ray energy; I is the transmitted gamma-ray energy after passing through x cm of lead; α_0 is the energy of the original gamma-ray photons incident on the lead slab; $\mu_l(\alpha_0)$ is the total linear absorption cross section in lead for the gamma ray of original energy α_0; and $B(x)$ is a numerical factor which accounts for the effect of the multiply scattered gamma rays that get through the thickness x cm.

Calculations indicate that the beam consists largely of photons that have been scattered through small angles. The function $B(x)$ is practically independent of the energy of the incident photons for α_0 = 1–5 Mev (*6*).

According to data from Mayneord and Cipriani (*7*) the average linear absorption coefficient in lead for the Co^{60} gamma rays is $\mu_l = 0.649$ cm^{-1}, based on density = 11.3 gm/cm^3. The half-value layer in lead consistent with this value of μ_l is 1.07 cm. With the above data, the attenuation of 8½-in. lead is computed to be 2.8×10^5.

To evaluate the reliability of attenuation calculations based on the table, measurements were made of the attenuation of the 8½-in. lead in the chamber. An open-air measurement of the radiation intensity was made at approximately 50 cm with a Victoreen thimble chamber which had been calibrated with a 300-mg source of radium. The thimble chamber was equipped with a ½-cm Lucite cap placed over the Bakelite portion. With chamber placed in the center of the access doorway with the door swung open, I_0 = 300 r/hr.

The attenuated level was determined by placing a number of calibrated films (Eastman type K) on the surface of the chamber. The film was calibrated by radium. The distance between source and film was the same as in the open-air measurement. The radiation levels that were obtained had a mean value of $I = 1.8 \times 10^{-3}$ r/hr. The measured attenuation is $(I_0/I)_{meas} = 1.65 \times 10^5$. This number is to be compared with the computed value $(I_0/I)_{comp} = 2.8 \times 10^5$. The values of $B(x)$ given by Plesset and Cohen permit estimation of I_0/I to within a factor of 2 for an attenuation of the order of 10^5.

Due to the self absorption of the cobalt the actual radiation output of the source is considerably less than a computed value for 100 curies of Co^{60}. The measured radiation output as determined on July 1, 1952, was 0.84×10^6 r/hr at 1 cm, which is equivalent to the filtered (0.5 mm Pt) gamma-radiation output of 100 curies of radium.

* * *

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Radiation Intensities

. . . Source in storage	
At external surface of turret in line with source	3 mr/hr
At stem with top shielding (max.)*	8 mr/hr
At external surface of chamber	background
Inside working chamber	
Center (table level)	17 mr/hr
Outside a central area, 4 in. in diameter, at table level	1 mr/hr
. . . Source working	
At external surface of chamber	
Average general reading	1 mr/hr
Average reading in line with source	1 mr/hr
Average reading in line with upper joint	2 mr/hr
Average reading in line with lower joint	5 mr/hr
Conduit holes	1.5 mr/hr
Underneath chamber, against rotating shaft for table†	40 mr/hr
Inside working chamber	
Sample at maximum distance of 25 cm	30 r/min
Sample at minimum distance of 2 cm	5,000 r/min

* This position is normally at least 20 in. from personnel exposure point where level < 1 mr/hr.

† This position is normally inaccessible. Reading at lower extremity of outer circumference of chamber is 0.5 mr/hr.

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Performance of Lucite-Bonded Alpha-Scintillation Screens

Light-tight screens, rugged enough for portable alpha detection, can be made by pressing the phosphor into a Lucite backing and coating it with aluminum. Pressed screens operate as efficiently as deposited screens if the sensitive area does not exceed the photomultiplier field of view

By J. D. GRAVES,* L. A. WEBB, and R. H. DAVIS†
U. S. Naval Radiological Defense Laboratory, San Francisco, California

ONE OF THE MAJOR constructional difficulties encountered with alpha and soft X-ray scintillation detectors is the necessity of shielding the phosphor screen and photomultiplier tube from extraneous light. A portable detector requires a rugged covering for the phosphor which is opaque to light but transparent to the ionizing radiation. Thick, unbacked, metallic-foil shields, while reasonably rugged, produce considerable attenuation. Thin metallic foils are delicate and generally unsuited to portable instrumentation.

A method has been developed for preparing Lucite-bonded scintillation screens which are light-opaque, transparent to ionizing radiation, and of rugged construction. The screens consist of a Lucite window with a phosphor coating molded in one surface under a thin film of aluminum. A considerable number of these screens, ranging in size up to 6 in. in diameter, have been used successfully in alpha-scintillation and soft X-ray detection.

* PRESENT ADDRESS: Radiation Engineering Laboratory, Stanford Research Institute, Stanford, Calif.
† PRESENT ADDRESS: University of California, Berkeley, Calif.

Construction

A 5% solution of Lucite in ethylene dichloride is poured on a horizontal glass plate. The phosphor (silver-activated zinc sulfide), in the form of a free-flowing powder, is dusted upon the surface from an atomizer. The particles do not sink into the liquid but stick on the surface. The result is a thin, even layer of phosphor which, after the solvent evaporates, is firmly attached to a film of Lucite. By altering the concentration of the Lucite solution and the rate of evaporation of the ethylene dichloride, the surface density of the phosphor can be varied from about 3 to 10 mg/cm^2. After soaking in water, the phosphor-covered Lucite film may be stripped from the plate, dried and cut to size.

Lucite backing. A backing in the form of a disk, cylinder or other shape is molded or machined from Lucite and is placed with the phosphor-coated film in a compression mold of the same shape. Since the surface of the mold in contact with the phosphor must be very smooth, a smooth portion of a ferrotype plate is placed between the surface of the phosphor and the body of the mold. The mold is then placed, with the phosphor-coated side of the screen down, in a press which will produce a pressure of about 2,000 lb/in.^{2} Placing the phosphor side down prevents the phosphor particles from settling into the Lucite.

The mold is heated to a temperature of about 135° C whereupon full pressure is applied. Pressure is maintained for about 10 min at the maximum temperature to insure a mirror-smooth finish to the phosphor-coated surface of the Lucite. The mold is then allowed to cool to below 40° C under full pressure. If insufficient temperature, time, or pressure is used, the surface will be dull and pitted and unsuitable for metallic coating.

Aluminum coating. The ferrotype is removed from the mold and coated with a small quantity of paraffin dissolved in benzene. The plate is polished until no visible trace of paraffin remains, after which it is coated by means of vacuum evaporation with a 0.4-micron layer of aluminum. This aluminum surface is washed with a 0.25% solution of Formvar in ethylene dichloride and dried on edge.

The ferrotype plate and screen are then reassembled in the mold with the aluminum facing the phosphor coat, and are heated, pressed and cooled as before. Upon removal from the mold,

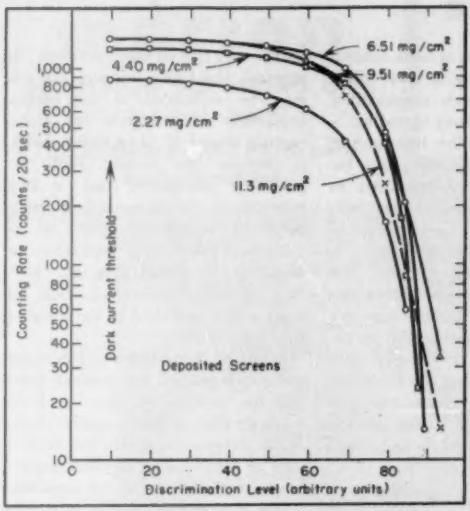

FIG. 1. Counting rate (Pu α-particles) of a deposited-screen scintillation counter as a function of the discrimination level for various screen thicknesses

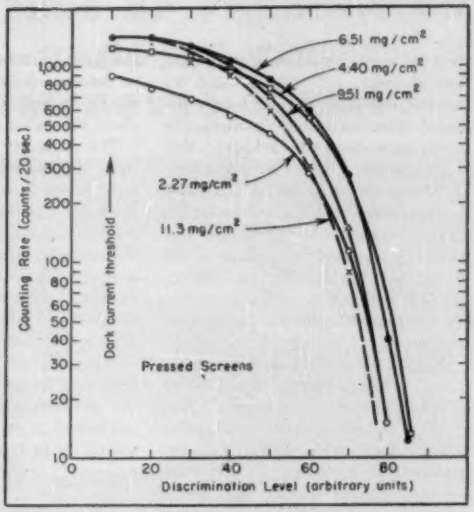

FIG. 2. Counting rate (Pu α-particles) of a pressed-screen scintillation counter as a function of the discrimination level for various screen thicknesses

the aluminum adheres quite strongly to the Lucite screen.

The resulting aluminum-coated screen, however, is not completely opaque but contains numerous pinholes. These are covered by washing the screen with a 1% solution of polystyrene in benzene, allowing to dry on edge, and then aluminizing as before directly upon this new surface. As a result the aluminum coat on the screen is mirror-smooth, entirely opaque and rugged enough to resist light scraping with the fingernail.

Curved screens. For some applications it is desirable that a screen be bent to fit a curved surface. This is not possible with heavily backed screens since bending splits the aluminum coating. For this reason it is necessary to fabricate screens of only a few thousandths of an inch thickness which can be bent to fit the curved surfaces. Where such a screen is desired, a sheet of cellophane is placed between a thin Lucite film and the thicker backing before pressing. The cellophane prevents the Lucite surfaces from sticking together and allows the thin screen to be stripped off after the process is completed.

Stopping power. The aluminum, Formvar and polystyrene layers covering the phosphor have a total thickness corresponding to about 1 micron of aluminum for alpha absorption. For 5-Mev alphas the attenuation is a very small percentage of the total energy. This slight energy loss is more than compensated for by the reflectivity of the aluminum surface. Increases in pulse height as great as 25% attributable to the aluminum have been observed in some cases.

Bonded screens have also been utilized successfully in soft X-ray detection. The high absorption of soft X-rays by any material makes the detection of this low-energy radiation difficult. However, with these thinly aluminized screens, where the low surface density of the metallic covering offers a minimum of absorption, X-ray energies as low as 430 volts have been detected.

Screens have been made using gold, copper, zinc, cadmium and tin films. Good results have been obtained also with different phosphors, such as copper-activated zinc sulfide, copper-activated zinc cadmium sulfide, and silver-activated sodium chloride for alphas, and calcium tungstate and cadmium tungstate for soft X-rays. Other materials may be included.

Experimental

Since the characteristics of a detector are a function of its application and the many parameters of design, it is desirable that an experimental arrangement used for the determination of screen characteristics should also provide the detection characteristics of the particular configuration of detector elements. In our case, the conditions set up and the configuration of the detector elements used approximated the use of alpha-survey detectors for monitoring areas comparable in size to the field of view of the photomultiplier.

Lucite screens 1 in. in diameter by ¼-inch thick were used. Two sets of five screens ranging from 2.27 mg/cm² to 11.3 mg/cm² were constructed. The phosphor was pressed into one set in the manner described above and was deposited on the second unpressed set for purposes of comparison. An RCA 1P21 photomultiplier tube and an uncollimated plutonium alpha source, ¼ in. in diameter of about 6,000 cpm, were used. The screens were inserted between the photomultiplier and the alpha source so that the Lucite face was tangent to the photomultiplier.

Results

Integrated pulse-height distribution curves were plotted from data taken for the deposited screens (Fig. 1) and for the pressed screens (Fig. 2).

From Figs. 1 and 2 it may be seen

that all screen thicknesses except the two thinnest, 2.27 mg/cm² and 4.4 mg/cm², produce the same total number of pulses for relative discrimination levels below about 20. It appears that extrapolation of these curves to a zero-discrimination level would not result in coincidence with the curves for the heavier screens. As the ZnS is particulate, coatings less than about 5 mg/cm² thick exhibit a noncontinuous distribution of the phosphor. Therefore the two thinnest screens were not considered further.

A general reduction in the counting rate at higher discrimination levels is observed with the pressed screens (Fig. 2) as compared to the deposited screens (Fig. 1). Nonradiative absorption of a portion of the energy of the alpha particles within the Lucite accounts for the shift of the curves in Fig. 2 to the lower discrimination levels. A variation in the percentage of alpha-particle energy absorbed in the Lucite accounts for the change in shape in the comparison between the pressed and deposited screens. If all the alpha particles were attenuated equally in the Lucite, only a shift in position could be observed, and the percentage reduction in discrimination level for the occurrence of any given counting rate would remain the same for the pressed and deposited screens. From Figs. 1 and 2 it may be seen that the attenuation in discrimination levels for pressed and deposited screens of equivalent weight ranges from about 10% at high discrimination levels to about 40% at intermediate levels. In no case for pressed screens above about 5 mg/cm² is all of the alpha-particle energy expended in the Lucite.

Counting efficiency. The counting efficiency—the ratio of the counting rate to the total counting rate as a function of the screen thicknesses—is observed to be a function of the discrimination level for both pressed and deposited screens. In both cases the screens 6.51 mg/cm² thick produce counting rates equal to or greater than those of any other thickness from discrimination levels of 10 to about 87 for the deposited screens (Fig. 1), and from 10 to 75 for the pressed screens. At higher discrimination levels, screens of other thicknesses are seen to be more efficient. Such a change, expected with an uncollimated source for phosphor thickness less than the range of the alpha particles, is of little concern in detector design, as it takes place at discrimination levels considerably above the region of likely operation.

The proximity of the 4.40-mg/cm² curve to the 6.51-mg/cm² curve for the pressed screens as compared to those for the deposited screens indicates that the most efficient phosphor thickness for the pressed screens is somewhat lower than that for the deposited screens, and somewhere between 4.40 mg/cm² and 6.51 mg/cm². This result would be expected, as the configuration of the detector in both cases may be considered identical, and the alpha energy available for light production is reduced in the pressed screens owing to absorption in Lucite.

Discussion

Pressed screens will be considered for monitoring prepared alpha sources of small dimensions, and for survey of extended areas where the screen is comparable in size to the field of view of the photomultiplier and where the field of view of the tube is extended to utilize large screens.

Prepared α-sources. In general, prepared laboratory alpha sources, with dimensions small compared to the field of view of the photomultiplier (for example, RCA 5819), would produce a much less variant pulse-height distribution than those shown in Figs. 1 and 2. The discrimination level at which the counting rate drops below the total counting rate observed at the dark-current level would therefore be greater. As a result, the signal-to-noise ratio which could be tolerated before an appreciable reduction in counting rate occurs would be even smaller than the factor of two found in the experimental case described. A large range of alpha-particle energies and screen thicknesses as well as the considerable variation in signal-to-noise ratio observed from phototube to phototube would not affect the counting efficiency. The pressed screens could be used successfully under such conditions.

Screen comparable to field of view. As evidenced by Fig. 2, pressed screens may be used successfully under conditions where the screen is comparable in size to the field of view of the tube. A 50% reduction in the signal-to-noise ratio can be tolerated without a reduction in counting efficiency. The source conditions of this experiment represent only a very special case, however. In practice, the alpha-emitting material may be embedded in the surface sufficiently to attenuate the alpha-particle energy to some extent before it reaches the screen. With the particular phototube used, a 50% reduction in the alpha-particle energy before it reaches the screen can be tolerated before any reduction in counting rate occurs (Fig. 2). At a 75% reduction in alpha-particle energy, a 12% reduction in the counting rate occurs.

Extended field of view. The limitations imposed by the present tubes and the need to monitor low levels over extended surfaces frequently bring about designs in which the field of view is extended by optical means.* A greater frequency of low-amplitude pulses in such cases results in a pulse distribution of greater variation than those in Figs. 1 and 2. It is under such circumstances that the reduction in pulse height, observed in the pressed screens, affects the counting efficiency.

In any detector configuration, the percentage change in counting rate or discrimination level between the pressed and deposited screens as a function of counting efficiency in either of the screens will remain constant. Although the tolerable drop in detector efficiency cannot be predicted here, the probable minimum detector efficiency would be 75%.*

Observation of the discrimination levels at which counting efficiencies greater than 75% occur in the pressed screens relative to the deposited screens gives an indication of the allowable relative decrease in pulse height. From Figs. 1 and 2, the ratio of discrimination levels of the pressed to the deposited screens for 90% counting efficiency is seen to be about 3 to 5. The ratio at 75% counting efficiency is about 4 to 7. The rate and manner of drop-off of efficiency with increased screen area, however, cannot be determined generally, and the suitability of the pressed screens must be determined for each specific detector configuration.

* * *

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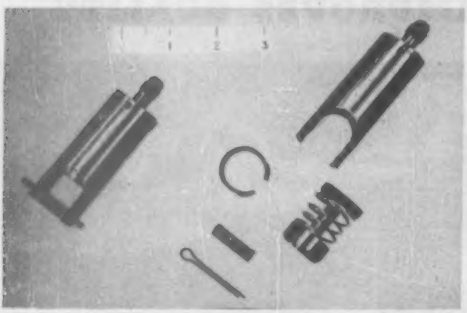

FIG. 1. Assembled and disassembled squeeze valves for use with flexible tubing

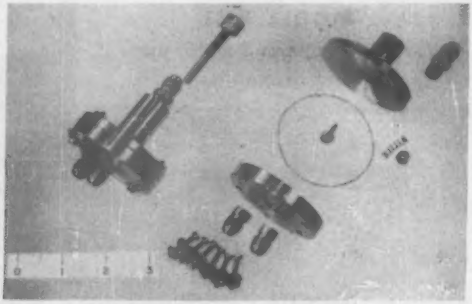

FIG. 2. Assembled and disassembled diaphragm valves for use with rigid tubing

Small Corrosion-Resistant Valves for Remote Chemical Service

By GERALD J. SELVIN*
Hot Laboratory Operations Group
Brookhaven National Laboratory
Upton, New York

In remote chemical processing of highly radioactive materials, valves are needed that are capable of remote operation and resistant to corrosion by all strong acids and alkalies up to 105° C. In addition, these valves should hold up not more than 2 ml of fluid in the valve body, be of small size and simple construction, have no packing or other potential sources of leakage, and should not cost too much when they are produced in moderate quantities.

Two valves have been developed. One, for use with flexible plastic tubing materials such as Tygon, meets all requirements except that of corrosion resistance. The other, for use when highly corrosive materials dictate the use of nonflexible tubing such as Kel-F, Fluorothene, Teflon, Saran, or stainless steel, meets all of the requirements.

Both valves are designed for compressed-air actuation. Building-service air pressures of 100 lb/in² are used, and air-line leaks other than complete line rupture do not nullify the action of the valves. Small-diameter Saran tubing is used for the air lines; lengths of 18 ft have been used. Hydraulic actuation was considered potentially dangerous since pressure-line leaks might cause complete failure of the entire valve system.

Squeeze Valve

A pneumatic squeeze valve for use on Tygon tubing with inside diameters of ¼–⅜ in. is shown in Figs. 1 and 3. Air pressure applied through the flare fitting forces the piston and plunger down against the tubing, squeezing it closed against the bottom block. The valve is opened by the return spring when air pressure is removed.

Continuous lengths of tubing can be inserted into the valve by removing the cotter pin and bottom block. The valve can be mounted on equipment with a chemical-equipment or a hose clamp. There is no reaction force from the valve to its mounting, and the unit is sufficiently light to permit lightweight mounting supports.

Most of the parts of this easily decontaminated all-stainless-steel valve are made of standard stock sizes to eliminate machining. The tube body is stainless-steel tubing with an inside diameter of 1 in. The air plug, plunger, and bottom block are cut from a standard 1-in. stainless-steel rod. The Neoprene cup washer, snap ring, and stainless cotter pin are all standard. The stainless-steel spring was wound for the unit.

The air fitting, originally machined with a ¼-in. SAE standard flare to fit the Saran air line and standard flare nuts, will be modified in future valves to ⅛-in. tube SAE 45-degree or AN 37-degree flare.

Diaphragm Valve

A diaphragm valve for use with rigid tubing with outside diameters of ⅛–⅜ in. is shown in Figs. 2 and 4. Because the unit performed so well, it was modified for direct manual manipulation by use of the hand operation screw shown in Fig. 4. For remote operation, this screw is removed and an air line is attached to the flared air fitting in place of it.

In service, air pressure of about 55 lb/in² (gage), applied to the air side of the diaphragm, causes the raised

* PRESENT ADDRESS: Sylvania Electric Products Inc., Hicksville, New York.

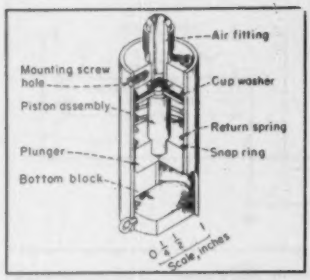

FIG. 3. Isometric view of squeeze valve

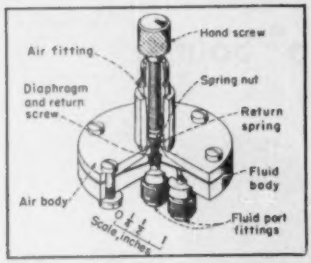

FIG. 4. Isometric view of diaphragm valve

plug molded into the diaphragm to seat against the fluid inlet port. Removal of air pressure permits the return spring to pull the diaphragm back to reopen the fluid ports. In the work for which the valves were developed, 55-lb/in² air pressure is used to close the valve completely against 25-lb/in² gas or fluid pressure. Other ratios could be used to suit the particular application of the valve.

For valving a vacuum line, the return spring is not sufficiently heavy. A modified three-way valve is then used to connect the vent port to either air-pressure or vacuum lines. The space behind the diaphragm can then be evacuated to equalize the vacuum on the system side of the diaphragm. The return spring then operates satisfactorily.

Type-304 stainless steel is used for the fluid and air bodies of this valve. Assembly welds are also of stainless steel, and are treated to prevent intergranular corrosion at the weld. The diaphragm is molded of Kel-F, with a stainless-steel screw molded in for the return spring action. Hardware and fittings are of types 303 and 304 stainless steel, respectively.

In future valves, the air fittings may be changed in the same manner as on the squeeze valve. Fluid fittings may be changed to ¼-in. Parker 37-degree flare. It is possible that investment casting of the fluid body could be used to eliminate welding operations and minimize machining.

* * *

The valves described here have been reported in Brookhaven National Laboratory report BNL-186 (1952).

Radioactive Building Tiles

By W. H. HOATHER
Derbyshire Royal Infirmary
Derby, England

During the course of a search for a lost radon seed, an appreciable activity was detected with a Geiger counter near the tiled wall of a long corridor (*1*). Further investigations showed that this activity came from some green tiles on the wall, and that it occurred in several corridors and rooms, etc., where this type of tile was used.

The green tiles were found to be radioactive, and their activity was due to the presence of uranium salts which had been used during the manufacture of the tiles. It is understood that a common practice at one time in the tile industry was to use uranium salts for obtaining good colors (e.g., green and orange). This practice has now been discontinued owing to restrictions on the supply of uranium.

Activity of Tiles

One of the green tiles was examined separately, and was found to give 690 cpm with a G.M. 4 counter placed 1 cm from the tile. A bench or wall lined with these tiles would therefore exhibit an activity corresponding to the maximum contamination permitted on a laboratory bench (*2*), and would render a room unsuitable for radioactive work. The radiation corresponds to a beta emission of about 2.1 Mev, and arises from the surface of the tile.

The activity is sufficient to fog a photographic film and hence it would not be possible to store films close to a wall or bench lined with these tiles. One film (Ilford No. 4) was blackened to a density of 0.9 when placed close to a tile for 16 days.

It has been found that a number of tiles used in domestic situations, such as fireplaces, bathrooms etc., are also radioactive. One typical orange-colored domestic tile was found to have an activity of 577 cpm with a G.M. 4 counter placed at a distance of 8 cm. (This activity is approximately four times the activity of the green tile when tested under similar conditions.) The orange tile was found to fog a photographic film in 6 hours.

Health Hazard

The green tiles are not regarded as a health hazard in their present surroundings, but more active tiles such as the orange ones might become a health hazard under certain conditions. The health hazard involved during the manufacture of the tiles, due to possible inhalation or ingestion, would appear to be limited by the fact that chemical toxicity arises at a lower concentration than that at which harmful radioactive effects would occur (*3*).

In view of the widely increasing use of radioactive materials in medicine and industry, and the increasing number of laboratories engaged in radioactive work, it seems desirable to draw attention to this possible source of radioactivity in building materials. It is evident that no radioactive tiles should be used in any buildings where radioactive measurements may have to be undertaken, and that in general the use of any radioactive substances in building materials should be avoided.

* * *

The author is indebted to Dr. H. Miller, of the Sheffield National Center for Radiotherapy, for providing facilities for some of the measurements.

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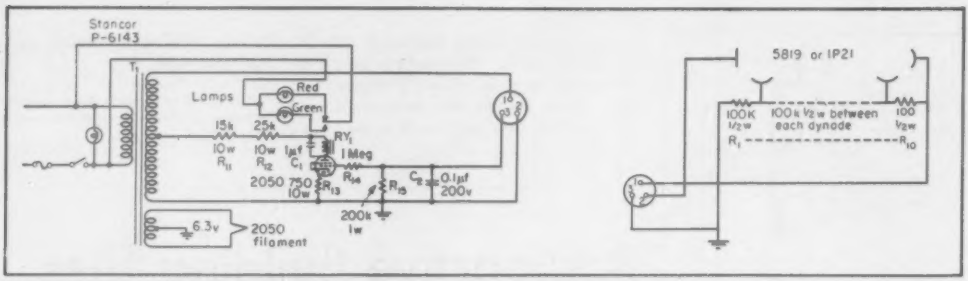
1. W. H. Hoather, *Brit. J. Radiology* **25**, 394 (1952)
2. Introductory manual on the control of health hazards from radioactive materials (Ministry of Supply, Atomic Energy Research Establishment, Harwell, England, 1949)
3. International recommendations on radiological protection, *Brit. J. Radiology* **24**, 50 (1951); also NUCLEONICS **8**, No. 1, 31 (1951)



CIRCUIT FOR SAFEGUARD DEVICE. Power supply and warning circuit are mounted on chassis; cable connects it to photomultiplier detector head inside irradiation chamber

Scintillation-Counter Safeguard for Co^{60} Source

By JACOB E. DIETRICH and WILLIAM R. KENNEDY
Electronics Section, Atomic Energy Project, The University of California
West Los Angeles, California

As an additional safety device for the Co^{60} irradiation unit described on page 65 of this issue, an electronic instrument has been designed and constructed that will warn the operators when the radiation level is unsafe in the working chamber. Personnel doing irradiation experiments must insert samples into the working chamber through an opened lead door either by hand or with tongs. Although a number of safety interlocks have been provided in the apparatus, there is a possibility that the Co^{60} may become detached from its support rod and fall into the working chamber. While ionization-chamber instruments are utilized when the door to the chamber is opened, a potential hazard still exists.

The scintillation-counter device described here gives a visual indication with warning lights of whether or not it is safe to open the chamber door. The instrument is simple, dependable, and in the event of failure will fail in the warning position. Space in the working chamber is at a premium, and the detector head is small.

A G-M detector external to the chamber was ruled out because other gamma-ray sources are used nearby. An internal ionization chamber could have been used in conjunction with suitable amplifiers to operate a warning device. But it is difficult to obtain long-time stability, as much as several days, with a line-operated d-c amplifier, and batteries are impractical.

Because of space limitations in the chamber, the 1P21 photomultiplier was chosen as the scintillation detector. The tube is enclosed in a light-tight housing that is fastened to the ceiling of the irradiation chamber. The calcium tungstate crystals are cemented to the envelope of the photomultiplier. The cable connecting the detector head to the power supply and warning unit is brought out through a shielded porthole in the chamber wall.

For simplicity, the photomultiplier and the thyratron in the warning unit are operated on alternating current. This eliminates the necessity for two separate power supplies with their rectifier-filter combinations.

The warning circuit is shown in the illustration. Power transformer T_1 with 440 volts rms each side of center tap furnishes the voltage for the 1P21 photomultiplier as well as voltage for operation of the relay in the anode circuit of the 2050 thyratron. Photomultiplier dynode voltages are furnished from a resistance divider, R_1 through R_{10}, across the outside terminals of the transformer. Relay RY_1 turns on either the red light when the detector is exposed to sufficient radiation, or the green light when little radiation is present.

The polarities in the circuit are such that the anode of the thyratron is negative with respect to its cathode during the half-cycle that the photomultiplier conducts in the presence of the radiation field. The time constant of $R_{14}C_2$ is arranged so that the capacitor retains enough charge to prevent the thyratron from firing when its anode has the correct polarity during the next half cycle.

The cabinet containing the electronic components is mounted on a shelf in back of the Co^{60} irradiation unit.

The unit has been in operation for only a short while, but it is believed that with the choice of components used it should continue to function satisfactorily. Circuit components have been adjusted so that the red warning light flashes when the Co^{60} source is just approaching the lower chamber through the opening of the shaft separating the storage and working chambers. Some effect of prolonged exposure has been noticed in that the relay takes several seconds to be activated after the Co^{60} source is removed. It has not been determined whether this effect is due to changes in the photomultiplier tube or the thyratron. It seems likely that this time lag can be eliminated by proper adjustment of the circuit constants.

• • •

This work was done under contract AT-04-1-GEN-12 with the U. S. Atomic Energy Commission.

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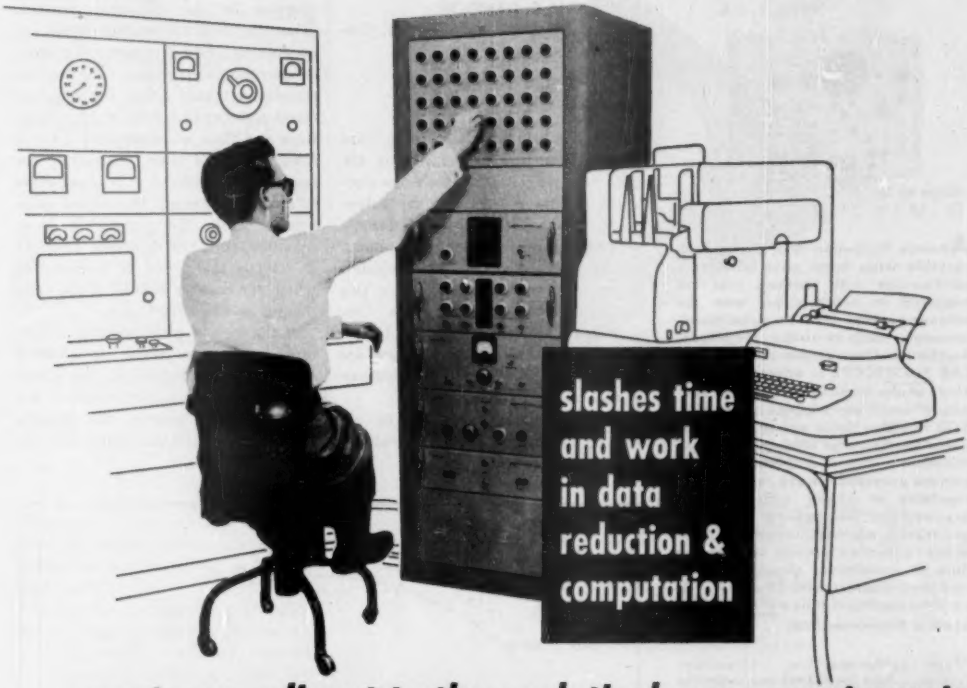

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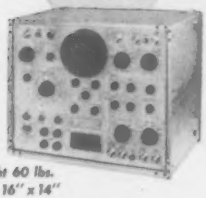

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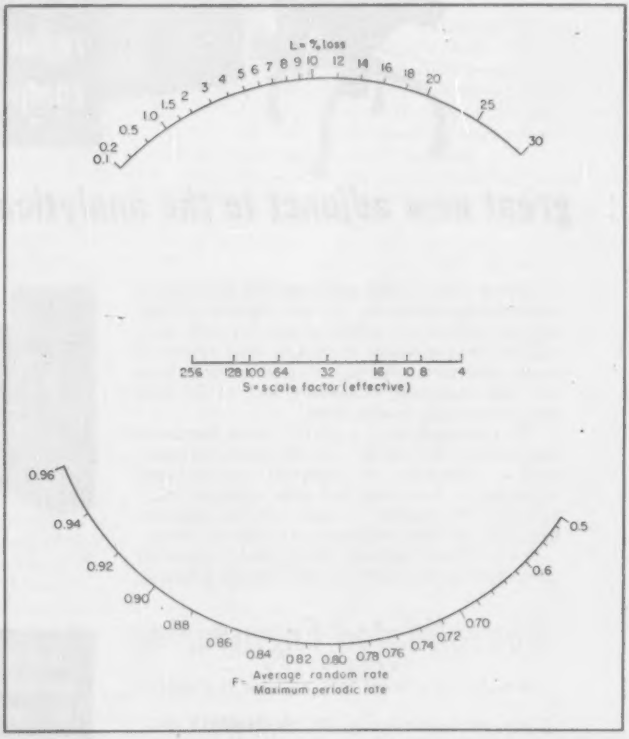
Nomogram for Computing Register Losses

By WILLIAM C. DAVIDON
Nuclear Instrument and Chemical Corporation, Chicago, Illinois

When counting random events, coincidence losses are introduced by the finite resolving time of both the electronic scaling circuit and the subsequent mechanical register. In most counting arrangements, the maximum counting rate is limited by the register. When counting at rates close to this maximum, the register loss predominates. Its magnitude will be discussed here. When both losses are small, the total loss is given approximately by their sum.

In most instances it can be accurately assumed that the register operates in the following manner. When the electronic scaling circuit has accumulated its full capacity of counts, it energizes the register. The register remains actuated either for a subsequent number of counts or for a fixed time and then is deenergized. For a fixed period of time, thereafter, the register is considered to be insensitive to any input pulse. If a second pulse occurs before the register is again sensitive, it is not recorded, although it extends the period of time during which the register is dead in the same manner as a recorded pulse.

If the register pulse lasts for a fixed number of input pulses, the effective scale factor is defined as the actual scale factor minus this number. For most standard binarys, the effective scale factor is half the actual since the



COUNTING ERROR caused by register losses can be computed with this nomogram

register pulse is obtained from the last binary. If instead, the register pulse is of fixed duration, the effective scale factor is equal to the actual.

For periodic pulses, there will be a maximum rate above which the register will stop counting.

For random input pulses, instead of an abrupt transition, the losses will continuously increase with input rate. If we let F = average random rate divided by maximum periodic rate, L = fraction of pulses lost, and S = effective scale factor, then

$$L = (2\pi)^{-\frac{1}{2}} \int_{(S/F)^{\frac{1}{2}}(1-F)}^{\infty} dy\, e^{-y^2/2} \quad (1)$$

This assumes that SF is much greater than 1 so that the Poisson distribution can be replaced by the Gaussian. Except for the scale-of-four at small F, this approximation is a good one. Letting

$$E(x) = (2\pi)^{-\frac{1}{2}} \int_0^x dy\, e^{-y^2/2} \quad (2)$$

we have

$$S^{\frac{1}{2}} = \frac{F^{\frac{1}{2}}}{1-F} \times E^{-1}\left(\frac{1-2L}{2}\right) \quad (3)$$

Equation 3 is in suitable form for the construction of a nomogram along the lines of that described by Adams and Evans.*

To use the nomogram, a straightedge is placed through any two known quantities and the unknown read off the intersection of this line with the scale corresponding to the unknown.

Example. A register capable of going 1,000 times per minute is to be operated with a standard scale-of-64 scaler. What is the maximum input rate for a register loss of 1%?

For a standard scale-of-64, the effective scaling factor is 32. The maximum periodic rate is 64,000 pulses per minute. From the nomogram, we obtain for an effective scale of 32 and 1% loss, a ratio of 0.67. Hence, the average random rate giving this loss is 0.67 × 64,000, or 43,000 cpm.

TECHNICAL BRIEF

● Vinyl floor tile does not always cold flow to seal its joints. In one laboratory, seepage from a spill contaminated the plastic subflooring. It was impossible to burn or scrape off the subflooring—air hammers were finally resorted to. Further trouble has been avoided by painting the floors.

* D. P. Adams, H. T. Evans, Jr., *Rev. Sci. Instr* **20**, 150 (1949).

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BOOKS

Symposium on Radiobiology

Edited by JAMES J. NICKSON (John Wiley & Sons, Inc., New York, 1952, xii + 465 pages, $7.50). Reviewed by L. H. GRAY, Medical Research Council, Radiotherapeutic Research Unit, Hammersmith Hospital, London.

This is a volume which radiobiologists have been eagerly awaiting—the proceedings of a conference held at Oberlin College in 1950. The conference set out "to make a thorough examination of the fundamental concepts that exist in radiobiology." There resulted 23 contributions, mostly packed with thought and information, which, in their total impact on the listener—if delivered in anything like the form in which they are presented to the reader—must have been quite overwhelming.

Under the able editorship of Dr. Nickson, they are presented in a volume which does much more than record the state of knowledge in 1950 on "The Basic Aspects of Radiation Effects in Living Systems," as the book is subtitled. During the past 25 years, those who have studied radiobiological damage at the cellular level have given their attention very largely to establishing the quantitative relations between morphological damage and the physical factors, such as quality, dose, and dose rate, of the radiation to which the cell is exposed.

This aspect of radiobiology is well presented in chapters by R. Latarjet, R. E. Zirkle, Titus Evans, and C. Tobias. That by Tobias gives, even now, the fullest account that has yet appeared of biological experiments with the 190-Mev deuterons from the Berkeley 184-inch cyclotron. Deuterons of this energy are traveling so fast that they should be classed not with the high-ion-density radiations but with X-rays. Indeed, on theoretical grounds their biological effectiveness would be expected to be, in most respects, roughly the same as 200-kv X-rays, and this is very beautifully demonstrated for certain types of damage in yeast. These particles are to be preferred to 200-kv X-rays for such investigations, because all the particles crossing the cell have the same constant rate of loss of energy which may be varied at will by a factor of 10. This greatly facilitates the interpretation of the results. These particles are used with good effect to confirm and extend the earlier work of Latarjet on the influence of ploidy on the radiosensitivity of yeasts.

The importance of chemical changes which proceed from the primary decomposition of water, and the rôle of chemical intermediates of short life, such as H, OH, and HO_2 radicals, are discussed at length by M. Burton, who deals with the elementary processes, and by E. S. G. Barron and W. M. Dale, who consider the resultant changes in molecules of biological importance. The accurate information concerning enzyme inactivation in dilute aqueous solution patiently accumulated by Dale over nearly twenty years, and the more recent build-up of this information by radiation chemists in many laboratories, tells us much about the sort of changes that are likely to follow upon the irradiation of living systems, but it is still a matter of almost pure speculation as to which, in fact, makes the major contribution to the initiation of radiobiological damage. The oxidation of SH groups of certain enzymes is uppermost in the mind of Barron.

That oxidizing radicals make a large contribution to radiobiological damage is evident from the important contributions of N. Giles and of A. Hollaender dealing, respectively, with the influence of dissolved oxygen on the induction of chromosome aberrations by X-rays, and with physical and chemical factors which modify radiobiological damage. It has not, however, as yet been conclusively demonstrated that there is any change in the number of oxidizable SH groups in tissue immediately after moderate doses of X-radiation, nor that tissues respire at a significantly different rate immediately after exposure *in vitro* to doses of radiation more than adequate to cause gross cytological damage in the same tissue.

These matters are discussed in a most stimulating manner by G. Hevesy, who places us all in his debt for the care with which he has reviewed over 140 investigations concerned with the influence of ionizing radiation on cellular metabolism. By virtue of his great knowledge, both of cellular physiology and of tracer methodology, Hevesy is a sure guide through this tangled branch of the subject. It is hardly possible as yet to relate any of the characteristic types of cytological damage to particular metabolic disturbances directly induced by radiation. There appears some hope, however, that new light may be shed on the temporary arrest of cells about to enter prophase by recent work on the energy requirement for cell division. By the use of tracer methods, it has now been established for a variety of tissues that the incorporation of phosphorus into desoxyribonucleic acid is profoundly disturbed shortly after exposure to quite small doses of radiation. Hardin Jones reports original experimental work in this field, including examples of the depression of DNA synthesis in liver and tumor tissue, following the selective irradiation of muscle by radioyttrium colloid.

H. J. Muller contributes a long chapter on the production of gene mutations by irradiation, in which the experimental findings, culled from more than 20 original papers of his own and 70 from other workers, are collated and freely intermingled with speculation as to the physical and chemical mechanisms whereby spontaneous and radiation-induced gene mutations arise. This makes good and provocative reading. The statement that "work has gone so far as to make it inconceivable, on physicochemical grounds, for a single ionization track traversing a nucleus to be without its proportionate probability of inducing a gene mutation" is an important conclusion to all concerned with the assessment of the genetic hazards of radiation, since it expresses Muller's conviction that the dose-mutation frequency relations may confidently be extrapolated downwards to the lowest doses. It is the more important since, as both Muller and W. L. Russell emphasize, experiments with mammals are so costly that they cannot possibly do more than check, at a few selected points, the conclusions drawn from studies with flies, molds, bacteria, and other organisms with short life cycles. Russell's handling of mammalian radiation genetics is very informative. In the light of his own experimental work, he gives a clear and convincing numerical assessment, at least as to order of magnitude, of the genetic hazard incurred by an exposed population.

A. Brues and G. Sacher discuss radiation injury and lethality in a new light by the use of the Gomperts function, which relates the logarithm of mortality to age. They show that if death

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from lymphoma (in mice) is excluded, the effects of chronic exposure are to reduce viability in such a way as to leave the Gompertz function linear, as in controls, but displaced or with altered gradient. Two different forms of chronic exposure which have been examined in detail were found to summate. Death from lymphoma follows an entirely different course.

P. Morrison, U. Fano, R. Wilson, A. K. Solomon, and R. Platzman, who were given the less exciting assignment of providing the background information in pure physics, nevertheless contribute chapters which are a very valuable part of the whole book. One could have wished that Fano, who has a particularly good grasp of what is relevant to the interpretation of biological phenomena, had written at greater length. There follow chapters by R. Livingston, and by M. Wallenstein, A. Wahrhaftig, H. Rosenstock and H. Eyring, which present the fundamentals of chemical theory with equal clearness. It is unfortunate that, in discussing the physical and chemical processes underlying radiobiological change, we are still compelled to rely very largely upon inferences drawn from studies in gaseous systems. These essayists subject the validity of the inferences to a more searching criticism than most of their predecessors have done.

BOOKS RECEIVED

The Elements of Nuclear Reactor Theory, by Samuel Glasstone and Milton C. Edlund, D. Van Nostrand Company, Inc., New York, 1952, vii + 416 pages, $4.80. Book based on course given at the Oak Ridge School of Reactor Technology and prepared under contract with the Atomic Energy Commission. (*To be reviewed.*)

Modern Radiochemical Practice, by G. B. Cook and J. F. Duncan, Oxford University Press, London, 1952, xx+ 407 pages, $8.50. A text on the practical aspects of the subject, primarily for chemists. (*To be reviewed.*)

Mesons—A Summary of Experimental Facts, by Alan M. Thorndike, McGraw-Hill Book Company, Inc., New York, 1952, viii + 242 pages, $5.50. Volume in International Series in Pure and Applied Physics. (*To be reviewed.*)

Basic Methods in Transfer Problems (Radiative Equilibrium and Neutron Diffusion), by V. Kourganoff with collaboration of I. W. Busbridge, Oxford University Press, London, 1952, xv + 281 pages, $7. Volume in International Series of Monographs on Physics. (*To be reviewed.*)

Photoelectric Tubes, by A. Sommer, John Wiley & Sons, Inc., New York, and Methuen & Co., Ltd., London, 1951, vii + 118 pages, $1.90.

Originally published as "Photoelectric Cells" in 1946, this pocket-size monograph has undergone considerable revision to bring it up to date. The chapter on photomultiplier tubes has been expanded to discuss their use in scintillation counters, and a new chapter on photoelectric emission has been added. In the chapter on "applications," the use of these tubes in particle detection work is discussed.

Development of the Guided Missile, by Kenneth W. Gatland, Philosophical Library, New York, 1952, x + 133 pages, $3.75.

A general, semi-technical review of British and American rocket developments, including missiles for high-altitude research. Nuclear-powered rockets are discussed briefly.

OTHER LITERATURE

Symposium on the Handling of Radioactive and Toxic Substances (report edited by G. R. Hall, published by Atomic Energy Research Establishment, Harwell). Proceedings of a conference held in England, 1951, for industry, university, and hospital personnel, at which the subjects of glove boxes, remote control of chemical operations, radioactivity-laboratory housekeeping, and decontamination were discussed (35 pages of text and 31 pages of illustrations). *Her Majesty's Stationary Office, 423 Oxford St., London W.1, 12s. 6d.*

Handbook on Air Cleaning (Particulate Removal), prepared by S. K. Friedlander, L. Silverman, P. Drinker, and M. W. First. Sponsored by the School of Public Health of Harvard University and the U. S. Atomic Energy Commission, this 89-page reference was designed to give AEC personnel information on current air-cleaning methods and criteria for judging their effectiveness; the text is confined to particulate matter only. The behavior of aerosols in air cleaning, performance and evaluation of equip-

ment, and special problems in the cleaning of radioactive aerosols are covered. *GPO, Washington 25, D. C., $0.45.*

Oak Ridge Institute of Nuclear Studies, Sixth Annual Report. An excellent summary in 50 pages of all operations of ORINS, its 30 participating universities, governing bodies, training programs, graduates, medical and exhibits divisions, and financial status—for the year ending June 30, 1952. *Oak Ridge Institute of Nuclear Studies, Oak Ridge, Tenn.*

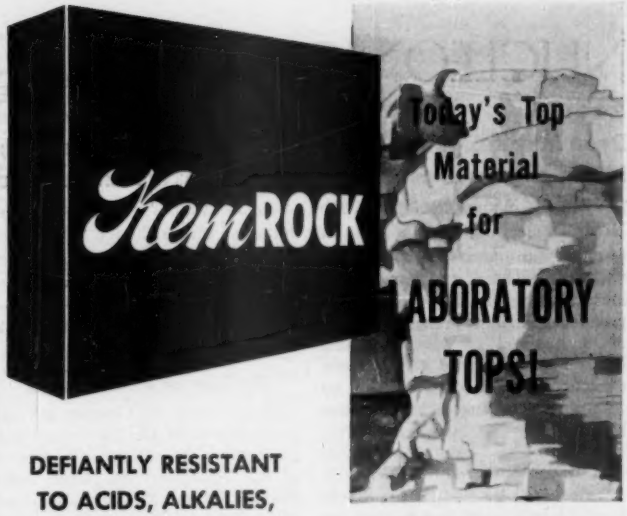
Symposium of Physiological Effects of Radiation at the Cellular Level. A 233-page reprint of nine papers and discussions given at an AEC research conference for biology and medicine, April 12–13, 1951. Monograph available without cost to scientific investigators in the radiation biology field; address: *Biology Division, Oak Ridge National Laboratory, Post Office Box P, Oak Ridge, Tenn.*

Interim Guide for Design of Buildings Exposed to Atomic Blast. A 34-page booklet for architects and engineers. *GPO, Washington 25, D. C., $0.15.*

Locating Common Electrical Faults in X-ray Generators. A chart, 11 × 15 inches, showing 9 trouble symptoms, 14 possible locations, 31 trouble possibilities, and the corresponding correction procedure, compiled to facilitate servicing of X-ray units. Available without cost from *Research & Control Instruments Division, North American Philips Company, Inc., 750 South Fulton Ave., Mount Vernon, N. Y.*

Tables of the Bessel Functions $Y_0(x)$, $Y_1(x)$, $K_0(x)$, $K_1(x)$, $0 \leq x \leq 1$ (National Bureau of Standards Applied Mathematics Series 25). A 60-page reissue (supersedes AMS1), with minor corrections, of extensive tables of Bessel functions used by nuclear technologists and other design engineers and physicists. The tables are computed at closer intervals than other existing tabulations of these functions, providing greater accuracy, over most of the range, by linear interpolation. *GPO, Washington 25, D. C., $0.40.*

National Bureau of Standards, Annual Report 1951 (Miscellaneous Publication 204). A broad picture of all NBS work and activities is given in this 105-page year-end report for 1951. Of special interest is section on the Bureau's work in radiation physics. *GPO, Washington 25, D. C., $0.50.*



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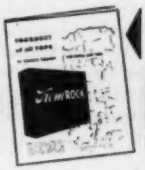

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NUCLEONIC EVENTS

Dean May Resign AEC Chairmanship Because of Election; New Congress Expected to Push Changes in McMahon Act

With the change in national administration that will result from the Nov. 4th election, Gordon Dean has indicated that although he plans to remain as a member of the Atomic Energy Commission, he may resign the chairmanship. Although AEC does not think the election will have much effect on its operations, it does pose some problems, primarily matters of organization of the commission itself. The election of a Republican Congress may have more effect on AEC than the change in the executive branch.

Status of Chairman

This will be the first time in AEC's history that it has undergone a change in Presidents, and thus there is no precedent for the status of the chairman. Members of AEC are appointed by the President and confirmed by the Senate. The chairman, however, is chosen from among the commissioners by the president, with no Senate confirmation asked.

In the case of such organizations as the Federal Power Commission and the Securities and Exchange Commission, where the chairmen are chosen by the President from among the Senate-confirmed commissioners, and are not confirmed as chairmen by the Senate, it is traditional that the chairmen tender resignations after a change in administration.

Other agencies of the government, such as Tennessee Valley Authority and Rural Electrification Administration, have chairmen who are appointed for specific terms by the President and confirmed by the Senate. Their tenure is unaffected by change in the administration.

Vacancy on Commission

Another problem for AEC is the vacancy left by the recent resignation of T. Keith Glennan (NU, Nov. '52, p. 105). It is possible that President Truman will leave this vacancy to be filled by General Eisenhower. In this case, a Republican might be appointed to replace Glennan, and then be named chairman. Dean is a Democrat. Since AEC has operated with less than full membership in the past, this delay in filling the commission vacancy would create no serious operating difficulties.

Revision of McMahon Act

The change in the Congress may put more pressure on AEC to come up with its own recommendations for revision of the McMahon Act. Even under the late Senator McMahon, the Joint Committee on Atomic Energy had warned AEC to come up with some amendments by the next session of Congress. There was an implied threat that if AEC failed to do so, the committee would draw up some of its own. Senator Bourke B. Hickenlooper, Iowa, who may be chairman of the joint committee, and other Republican committeemen feel strongly that legal opportunities for private industry in the atomic energy field should be broadened. Senator Hickenlooper was chairman in the 80th Congress. There is some speculation, however, that Representative W. Sterling Cole, N. Y., may become chairman.

Some AEC officials question the advisability, at this time, of attempting to draft legal standards for answering such questions as which firms, or groups of firms, should be permitted to undertake nuclear power projects, what type of controls must the government maintain over the use of fissionable materials, and at what point does a private firm deserve a patent for developments on which primary research was performed with private funds.

The McMahon Act forbids private ownership of facilities for production of fissionable material in any significant quantity. This clearly forbids private construction and operation of a dual-purpose reactor, the type that has been judged by industrial groups as holding the most promise for future private ownership. The Act has also removed from the patent system the bulk of atomic development, including the area of most interest to would-be private operators of nuclear power plants.

For the present, at least, AEC would prefer to have Congress give it broad authority to set its own standards in these areas. Some AEC officials have said they would like to get a grant of such authority for a period of 3–5 years. At the start of the forthcoming hearings, due to get underway in February, AEC attorneys are likely to urge such a solution. Congress, however, probably will not like the idea.

Study Peacetime Uses of Hydrogen-Bomb Reaction

Efforts at finding peacetime uses for the thermonuclear reaction were hinted at last month by Harold C. Urey, Nobel Prize winner in chemistry from the University of Chicago, and a leading figure in atomic energy work.

A classified meeting to discuss the problem of nonmilitary applications of the thermonuclear reaction was held last spring under Atomic Energy Commission auspices, and some preliminary work is under way. Actually, at this point, work on the hydrogen bomb, as with the A-bomb, will also give valuable information for peacetime uses.

Army May Build Nuclear Power Plant

The U. S. Army may put in a bid for one of the first nuclear power plants to be developed. That's the reason for the recent assignment of Col. James B. Lampert of the Corps of Engineers as a liaison representative with the Atomic Energy Commission.

Col. Lampert, under arrangements made by AEC chairman Gordon Dean and Army secretary Frank Pace, Jr., is working directly with AEC's reactor development division. For the time, at least, he is simply surveying existing projects with an eye toward possible military applications for nuclear power. His findings will determine if the Corps of Engineers, the branch responsible for supplying electric power at army installations, will get into nuclear power development on its own.

Prime objective of the Engineer

Corps at present is to determine the feasibility of nuclear power at overseas military bases in event of a war or Korean-type campaign. Savings in transportation cost for fuel for a conventional electric power plant at such bases might be very large, Secretary Pace pointed out.

Secondarily, the armed services are interested in nuclear plants as a source of power at permanent installations, such as those we maintain in the Arctic and in other inaccessible regions.

Last month, in NUCLEONICS, Alvin M. Weinberg, director of research, Oak Ridge National Laboratory, suggested just such an idea—that small nuclear power plants be constructed for use in remote localities where power is now very expensive (NU, Nov. '52, p. 31).

AEC to Ask for $1-Billion for Fiscal 1954

Appropriations for the Atomic Energy Commission for fiscal 1954, which starts July 1, 1953, are expected to be smaller than either the regular appropriation for fiscal 1953 or the supplementary expansion appropriation passed during the summer. However, the total amount of money that AEC spends in fiscal 1954 will probably be about $1-billion more than the $2.1-billion it is spending in 1953.

The relation of appropriations to actual spending by AEC isn't readily apparent. Since its inception, AEC has been permitted to carry over unexpended funds, particularly for new construction, from year to year. Last year's supplemental appropriation will be spent over a period of four years.

The annual appropriations request by AEC will, as usual, be a carefully guarded secret up to the hour it is announced next January in the President's annual budget message. But it is now known that AEC will ask Congress for about $1-billion.

This is somewhat less than the $1.1-billion in regular appropriations which AEC has for the current year (NU, July '52, p. 76), and much less than the supplementary $2.9-billion awarded AEC for plant expansion (NU, Aug. '52, p. 74). The difference in spending between 1953 and 1954 will come from the supplementary plant expansion funds.

The spending estimate of $2.1-billion for fiscal 1953 represents a drop in previous calculations by AEC. The last previous estimate fixed probable expenditures at $2.4-billion. The new figure apportions about $800-million to operating costs, and the remaining $1.3-billion to plant and equipment.

Next year's operating costs figure to be about the same as for the 12 months ending in June. The commission expects that next year it will spend upward of $1.6-billion on the new plant in Portsmouth, Ohio (NU, Sept. '52, p. 67), and on expansion of the plants at Paducah, Ky., and Oak Ridge, Tenn. That's what it told the Congressional appropriations committees last summer. This was to be in addition to spending for new plant and equipment at other locations.

Appropriations Committee Investigates AEC Spending

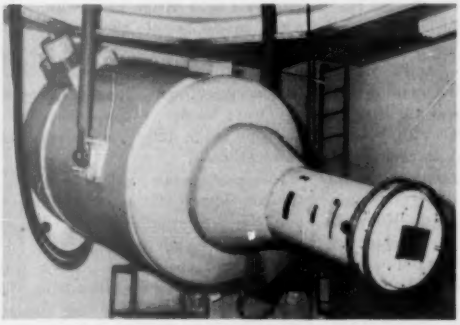
Fiscal procedures at all Atomic Energy Commission facilities are under investigation by the House appropriations subcommittee that handles AEC money. The investigation is being directed by Congressman Albert Thomas (D., Tex.) chairman of the subcommittee.

The working staff are government people, accountants, lawyers, and construction engineers, borrowed from agencies like the Navy, General Accounting Office, and Federal Works Administration. The 18 investigators who, with Thomas, have been traveling the circuit of AEC facilities, are not concerning themselves with anything except spending, and will not go into any operating procedures.

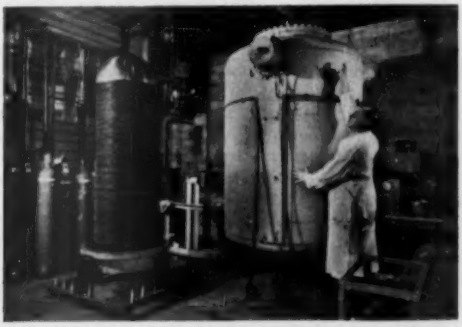
No statement on the findings will be made until about April.

Glennan Suggests Atomic Industry Association

Establishment of a national association of atomic industries, to work closely with the Atomic Energy Commission, the Joint Congressional Committee on Atomic Energy, and other



2-MEV X-RAY GENERATOR, at Hospital for Joint Diseases, New York City, operates on resonating transformer principle. It can be directed with three degrees of freedom which permits rapid change-over from multiple-field to rotation therapy techniques. At 100 cm from target, and at 2 Mev and 1.5 ma (4 mm added Pb filter) the output is 108 r/min in air, constant to better than 2%. Under these conditions, the half-value layer is 6.8 mm Pb, and the calculated average energy is 1.35 Mev for the continuous spectrum with a 2.0-Mev maximum



RESONATING TRANSFORMER AND HOUSING of the 2-Mev X-ray generator, which was built by General Electric Co. High-voltage coil, made up of thin flat laminations, has natural frequency of 180 cycles. Multisection X-ray tube, mounted in center of coil, is permanently evacuated and sealed. Steel tank, 5 ft in diameter and 8 ft long, is filled with SF_6 gas at 60 lb/in.^{2} for insulation. The 180-cycle exciting current comes from remote-controlled motor-generator on upper floor of building. Treatment room is 29 × 23 ft

appropriate government agencies, has been suggested by T. Keith Glennan, president of Case Institute of Technology, and former member of AEC.

In an address to the Manufacturing Chemists' Association, Glennan said the proposed organization should be established voluntarily and without governmental urging or subsidy by those industrial concerns that are today actively engaged in atomic research, development, and operations.

The association, whose broad aim would be to foster and encourage development and utilization of peaceful applications of atomic energy, should, Glennan said, have three major functions:

1. Provide a forum in which the atomic energy industry could arrive at an informed and perhaps common position on such matters as ownership of atomic energy facilities, rights to patents, licensing regulations, health and safety standards, secrecy policies, personnel clearance policies, and contract and tax procedures.

2. Provide a channel through which industry's position on these matters could be brought to the attention of AEC, Congress, and the public.

3. Provide a mechanism for acquisition and dissemination throughout industry of information on such matters as laws and regulations, business opportunities, and new technological developments.

Among the industries that should participate in such an association, Glennan suggested those engaged in production of source and fissionable materials, power production, industrial distribution and utilization of radioisotopes, design and construction of reactors and chemical processing facilities, and manufacture of equipment primarily useful in atomic energy work.

Release Details of New French Heavy-Water Reactor; Unique Cooling System Gives Very Efficient Fuel Use

PARIS (*McGraw-Hill World News*)—The second reactor in France, a heavy-water natural-uranium pile, went into operation last month at Saclay near Paris. Although to be used primarily for isotope production and research, the Saclay reactor, known officially as P-2, is capable of producing up to about 400 gm of plutonium a year.

Technically, the most interesting feature of P-2 is its unique cooling system which is said to be considerably more efficient than conventional types. The uranium rods are cooled by nitrogen gas at a pressure of ten atmospheres. The use of this system makes possible a yield of more power per ton of uranium.

Although officially said to produce 1,500 kw, the power of the Saclay reactor is more conservatively placed at 1,200 kw by Leo Kowarski, scientific director of the French atomic energy commission. Kowarski figures the production of plutonium on the basis of 1 gm plutonium daily for each 1,000 kw, which gives the figure of 400 gm of plutonium a year. The amount of plutonium actually produced, however, will depend on how much the reactor is used for other isotope production and research.

The neutron density of an experimental reactor—its value as a laboratory instrument—can be estimated from the amount of power it extracts from a ton of uranium. As designed, the Saclay pile is expected to produce 400 kw per ton of uranium, which far surpasses the 100–200 kw per ton produced by the air-cooled graphite reactors at Oak Ridge and Brookhaven.

According to Kowarski, the heavy-water reactor offers distinct advantages. With an equally efficient cooling system, and producing the same number of kilowatts per ton of uranium, a heavy-water reactor can be constructed with $\frac{1}{10}$ the metal needed for a graphite reactor and will dissipate only $\frac{1}{10}$ as much heat. Heavy-water reactors are also easier to cool, which increases their advantage as the power is increased.

For the cooling system, Kowarski points out that there is a choice of passing large quantities of cooling fluid over uranium bars kept at moderate temperature (about 200° C) or using less fluid and keeping the uranium at 400–500°C. For low temperatures, the cooling fluid must be pumped through under pressure. In the relationship between the temperature of the uranium and the pressure of the cooling fluid, Kowarski believes that the advantages lie with higher pressures rather than higher temperatures.

FELIX BLOCH and EDWARD M. PURCELL, winners of the 1952 Nobel Prize in physics

Bloch and Purcell Receive 1952 Nobel Physics Prize

The Nobel Prize committee added to the distinguished list of Nobel laureates in nucleonics when it awarded the 1952 physics prize jointly to Felix Bloch and Edward M. Purcell for their work on nuclear induction and resonance. The two men worked independently on the problems, heading groups at Stanford and Harvard Universities, respectively.

In both cases the work is based on the fact that since the charged nucleus of an atom has a certain intrinsic spin, it behaves like a small electromagnet, with its magnetic moment aligned with the direction of its spin. If this spinning nucleus is placed in a magnetic field, its magnetic moment will precess around the direction of the field the way a gyroscope precesses around the direction of the earth's gravitational field.

The material to be investigated is placed in an adjustable radiofrequency field which is perpendicular to the magnetic field about which the magnetic moments of the nuclei are precessing. The r-f field is varied until its frequency coincides with the frequency of precession. There are two ways to detect this coincidence, and this is the difference between the two methods.

In the resonance method of Purcell, the coincidence of the radiofrequency and the precession frequency causes some of the nuclei to reverse the direction of their spins. When this happens, energy is absorbed from the r-f source. Detection of this sudden absorption of energy identifies the particular radiofrequency for the nucleus involved, and thus determines the frequency of precession.

In the induction method of Bloch, a receiver coil is placed perpendicular to the magnetic and radiofrequency fields. A voltage is induced in this coil when the spin, and consequently

the magnetic moment, suddenly change direction. It is this voltage which is detected, rather than the resonance absorption of energy detected in the Purcell method.

The first simple application of these methods is as a means for measuring magnetic fields. If water is used as a sample, and since the magnetic moment of the proton is known accurately from other experiments, the magnetic field can be determined by measuring the frequency of precession. This method is, for many uses, a great improvement over older methods, and field measuring instruments based on this method have been put into commercial production.

Aside from such practical applications, the method has helped in understanding some of the basic problems about the interaction of nuclear particles, particularly the neutron, the proton, and the deuterium and tritium nuclei. When the methods are extended to more complicated nuclei, they promise to give much information about their structures.

The methods should also have a great future as means for investigating the properties of crystals and in applications to qualitative analysis in physical and organic chemistry.

This year, the prize carries a cash award of $33,037, which will be divided between the two men. The formal presentation was made by King Gustav VI of Sweden at Stockholm on Dec. 10.

In the original work on the methods, Bloch was aided by Martin Packard and the late William W. Hansen, and Purcell was aided by H. C. Torrey and R. V. Pound.

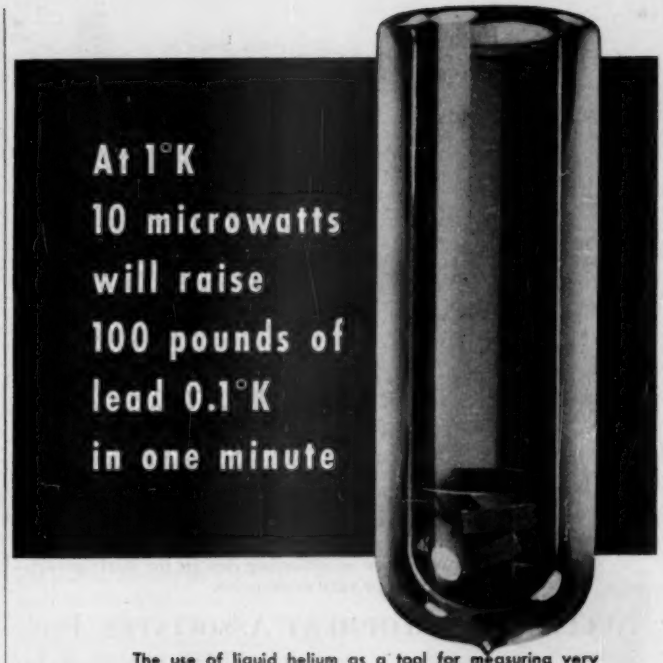
ORINS Announces Future Radioisotopes Courses

The Oak Ridge Institute of Nuclear Studies has made preliminary announcement of some courses to be given this coming year.

The 30th, 31st, and 32nd basic courses in radioisotopes techniques in research are scheduled to begin Jan. 5, Feb. 2, and March 2, 1953, respectively. The 33rd, 34th, and 35th courses will commence June 8, July 6, and Aug. 10, 1953.

An advanced course in applications of radioisotopes to industrial research problems will be given some time in the spring of 1953. This course will cover, among others, the fields of physics, chemistry, and metallurgy.

An advanced medical course is



The use of liquid helium as a tool for measuring very small heat influxes, suggested some time ago, has been reported on recently. By the use of a constant temperature calorimeter containing liquid helium, power levels of the order of a few microwatts can be measured. This is possible because of the almost zero values of specific heats near 4° K and the small latent heat of vaporization of liquid helium. Such a calorimeter has been used for the measurement of the total emissive energy of a β ray source, and it should also be of use in measuring low energy γ rays. A substantial amount of lead could be used at 4° K for absorption purposes, with little contribution to the heat capacity of the measuring system.

Directional effects in radioactive emission near .01° K have recently been reported from Oxford and Leiden as a result of the first successful experiments on nuclear alignment. Various similar experiments have been proposed, and, undoubtedly, in the near future, physicists will make much more use of temperatures near 0° K where the low energies of nuclear interactions become of importance.

The ADL Collins Helium Cryostat made by Arthur D. Little, Inc. is the basic tool in low temperature research. It liquefies helium and maintains a test chamber from normal room temperature to within two degrees of Absolute Zero. By using the adiabatic demagnetization process, the temperature can be further reduced as low as 0.0015°K.

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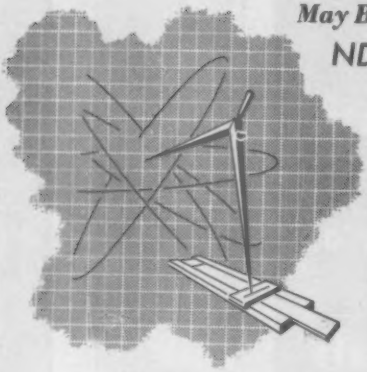

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planned for the summer of 1953, as is a course in autoradiography.

Additional information can be obtained from R. T. Overman, Special Training Division, ORINS, Box 117, Oak Ridge, Tenn.

IN BRIEF

• **Synchrotron patented.** E. M. McMillan has been awarded patent No. 2,615,129 for the synchrocyclotron which he designed and which has been built at Berkeley. The patent was granted despite acknowledgement by McMillan that the synchrocyclotron was independently developed by the Russian physicist, V. Veksler.

• **GE technicians.** Of the 11,000 employees working in the various atomic energy projects of General Electric Co., 5%, or 550, are technical people.

• **Human decontamination.** The Foster D. Snell Laboratories have studied decontamination of radioactive materials from human skin using human subjects.

• **Biomedical research.** Hazards and possible control measures for handling radioactive materials are the problems of a biomedical research program set up at Mound Laboratory, Miamisburg, Ohio. Studies will be done in chemical treatment for counteracting, imitating, or increasing radiation effects and the metabolic processes disturbed by radiation.

• **Mobile logging unit.** The AEC has bought a mobile unit for use in searching for radioactivity. The detecting element is a scintillation probe which is lowered into the ground. As the probe is withdrawn, the logging unit measures and records the activity at various levels. The unit was constructed by Bogue Electric Co., Patterson, N. J.

NUCLEAR NEWSMAKERS

Wolfgang Pauli has been awarded the Franklin Medal, highest honor of the Franklin Institute, for his work toward the understanding of atomic physics, and specifically for his formulation of the exclusion principle.

Cyril Stanley Smith, professor of metallurgy and director of the institute for the study of metals at the University of Chicago is the recipient of the Francis J. Clamer medal of the Franklin Institute. The citation states that the award is being given for his work

leading to the discovery of the basic factors in the metallurgical behavior of plutonium essential to the development of nuclear energy.

William G. Pollard, physicist, has started his second 5-year term as executive director of the Oak Ridge Institute of Nuclear Studies.

Carl C. Gamertsfelder is now with the aircraft nuclear propulsion division of General Electric, Co., Lockland, Ohio, where he will work with radiation problems and advise the hazard control group there. He has been succeeded as manager of the biophysics section at GE's Hanford Works by **Dennis W. Pearce.**

George E. Boyd and **Alan D. Conger** of Oak Ridge National Laboratory will spend the year in Europe as Fulbright scholars. Dr. Boyd, associate director of the ORNL chemistry division, will be a visiting research professor at the University of Groningen, The Netherlands. Dr. Conger, radiation geneticist, will do research at the Hammersmith Hospital, London.

Edith H. Quimby, department of radiology, College of Physicians and Surgeons, Columbia University, has been awarded the second Jagadish Bose Memorial gold medal by the Indian Radiological Association. Her memorial lecture was entitled "Recent Developments in Radiation Dosimetry."

Carl A. Benz has joined the research staff of the chemical plants division of Blaw-Knox Co. as senior physicist. He will assist in developing peacetime commercial uses of atomic energy.

MEETINGS

American Physical Society—Inyokern, Calif., Dec. 26–27; Pasadena, Calif, Dec. 29–30

American Association for the Advancement of Science, Annual Meeting—St. Louis, Mo., Dec. 26–31

American Chemical Society, Division of Industrial and Engineering Chemistry, 18th Annual Chemical Engineering Symposium—Evanston, Ill., Dec. 27–28

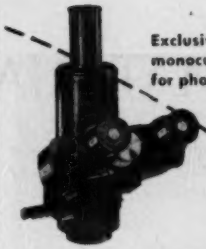
American Physical Society, Annual Meeting—Cambridge, Mass., Jan. 22–24

American Chemical Society, Division of Industrial and Engineering Chemistry, 19th Annual Chemical Engineering Symposium—Yale University, New Haven, Jan. 2–3

IRE-AIEE Western Computer Conference —Hotel Statler, Los Angeles, Calif. Feb. 4–6

American Physical Society—Durham, N. C., Mar. 26–28

American Physical Society—Washington, D. C., April 30, May 1–2



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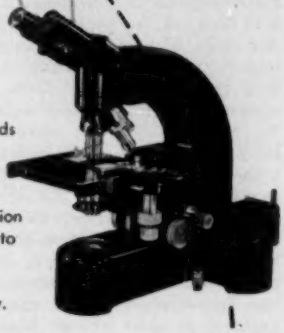

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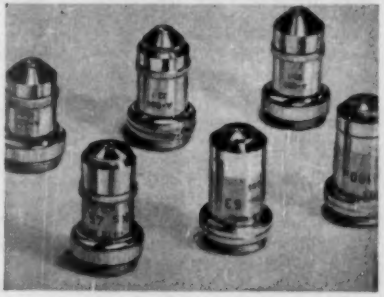

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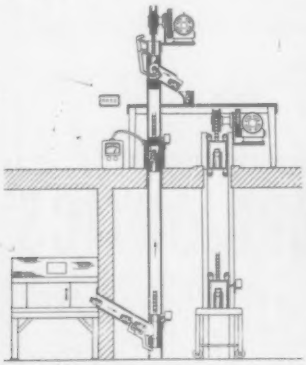
PRODUCTS AND MATERIALS

Portable Scintillation Counter

Precision Radiation Instruments, 2235 S. La Brea Ave., Los Angeles 16, Calif. The ranges of the model 111 portable scintillation counter are 0.025, 0.05, 0.25, 1, 5, and 25 mr/hr, with an accuracy of 5% of ¾ full-scale reading. No external calibrating control is needed. The instrument, employing a thallium-activated sodium-iodide crystal and an RCA 6199 photomultiplier tube, operates from −25° C to 40° C and is altitude independent to heights in excess of 15,000 ft. The probe, which operates on a range switch and time-constant switch, can be immersed in water without damage. Battery life is said to be in excess of 200 hr. Total weight of the instrument is 6 lb.



Radioisotope Conveyor

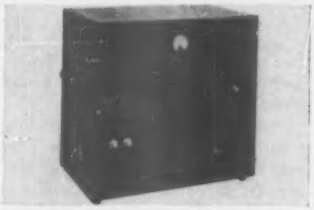
Bar-Ray Products, Inc., 209 25th St., Brooklyn 32, N. Y. This radioisotope conveyor system provides for the transfer of isotopes by remote control. Motor-operated lead dumbwaiters transport isotope containers in a vertical tube. Entrance of bottles into and ejection from the dumbwaiter are automatically effected. An ionization chamber measures gamma radiation at an automatic stopping point in the tube. A large dumbwaiter returns empty bottles.

Binary Counter

Walkirt Co., 5808 Marilyn Ave., Inglewood, Calif. The type M1552, 11-prong plug-in binary counter, designed for all types of counting and frequency division, has a range of 0–3.0 Mc. Input is 75-volt negative pulses with rise time of 0.2 μsec; output is 125 volts with rise time of 0.2 μsec. Power requirement is 17 ma and 250 volts. The counter, using a 5670 or 2C51 tube, is sealed and ruggedized.

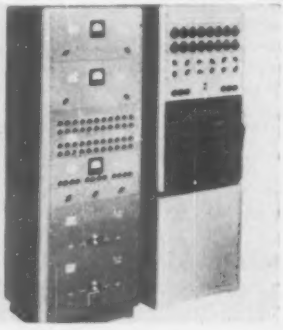
Regulated Power Supplies

Bristol Engineering Corp., Lincoln Ave. and Pond St., Bristol, Pa. The 400-series regulated power supplies are designed to be combined into multiple output systems providing up to ±1,200 volts. Relay control of plate and filament voltage allows convenient remote operation. Output of model 401 is 250–500 volts, d-c, at 200 ma, regulated, and 6.3 volts, a-c, at 6 amperes. Output of model 402 is 150–325 volts, d-c, at 200 ma, regulated, and 6.3 volts, a-c, at 6 amperes.



Low-Frequency Oscillator

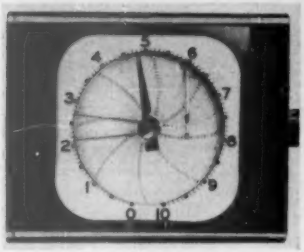
Southwestern Industrial Electronics Co., 2831 Post Oak Rd., Houston 19, Texas. The frequency of the model L low-distortion oscillator is continuously variable from 0.01–100 cps in eight overlapping ranges. Two output circuits are provided: one delivers 0.02, 0.2, 2, and 20 volts across 1, 10, 100, and 1,000 ohms, respectively; the other output has a constant internal resistance of 300 ohms and a 1-volt open-circuit voltage. Output voltage amplitude is constant to ±5% of entire range when operated with varistor and ±3% with thermistor.



Analog Computer

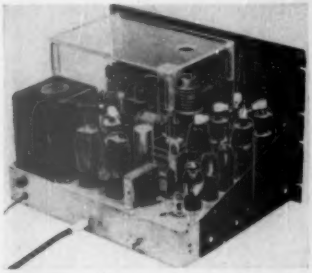
Beckman Instruments, Inc., Special Products Division, S. Pasadena 37, Calif. The low-cost EASE analog computer can solve 7th-order linear total differential equations and, with auxiliary equipment, many nonlinear equations. The computer also simulates the performance of natural or engineered systems while a variable is applied to the system, and can substitute for a dynamic system in testing subsystems and associated equipment. Basic components are: 10-channel operational amplifier and power supply

(computational accuracy of 1% per stage), 2-channel function generator, and function multiplier. Standardized or custom-made arrangements may be ordered.



Round-Chart Recorder

Bristol Co., Waterbury 20, Conn. Sensing elements that can be used with the round-chart Dynamaster recorders include radiation-detecting units, *p*H amplifiers, beta-ray gages, and thermocouples. The variable measured is simultaneously recorded on a 12-in.-diameter chart and indicated on a large circular scale. Models are offered for full-scale pen travel in 7, 3, 1½, or ¾ sec, and with a variety of ranges. Air-control and electric-control models are also available. Electronic components are easily accessible and completely interchangeable.



D-C Power Supply

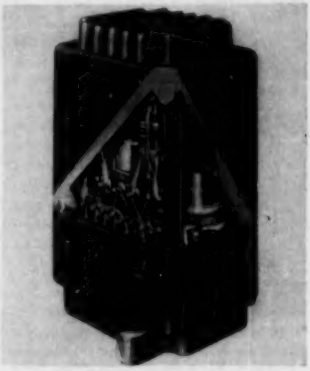
Spellman Television Co., Inc., 3029 Webster Ave., Bronx, N. Y. The model LAB30, r-f-type power-supply provides 1–30 kv, d-c, regulated to ½% of 1 ma. Up to 2 ma may be drawn from 20 kv down; output is continuously variable. The power supply is also available in a reversible polarity unit, model LAB30PE, having the same characteristics as the standard model.

Digital Graph Plotter

Logistics Research Co., 141 S. Pacific Ave., Redondo Beach, Calif. The Logrinc graph plotter records remote activities through impulses transmitted by wire or radio. It also serves as a read-out device for electronic digital computers. The plotting area is 12 × 18 in., or a continuous 12-in. strip of paper may be used. Steps are 1/64 in. along either axis; plotting speed is up to 20 steps per sec. No synchronization is needed between x and y inputs, since their actions are independent. Release buttons permit manual positioning of the ball-point pen; pen and drum releases also permit drawing coordinate axes. Power supply is self-contained.

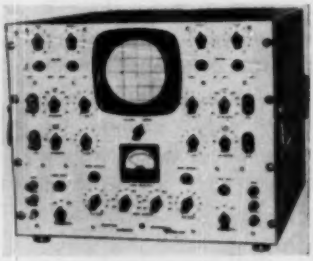
X-Ray Diffraction Unit

General Electric Co., 4855 Electric Ave., Milwaukee 14, Wis. The high-voltage transformer of the XRD-4 X-ray diffraction unit provides full-wave rectified, end-grounded voltage up to 50 kvp at 50 ma continuously. Tube current is stabilized to ±0.02%. Height of the tube target is adjustable from 8 to 13 in.; the focal spot in the tube is 1 in. from the beryllium window. The camera track can be adjusted from 0 to 10 degrees below horizontal for optimum target takeoff angle, and from 0 to 45 degrees above horizontal for use of crystal monochromators. Up to three cameras may be mounted on the top of the unit. A self-contained water cooler eliminates plumbing.



Circuit Assembly Unit

Technical Development Corp., 4070 Ince Blvd., Culver City, Calif. Unistage, a unit assembly providing from 1 to 4 tubes in any circuit combination, is designed to plug into an electronic device. The unit comprises a watertight aluminum housing, coded terminal board, tube plate, and tube well or wells. Heat dissipation is facilitated by the black anodized housing and cooling fins. Defective units are said to be replaceable within minutes.



Dual-Channel Oscilloscope

Electronic Tube Corp., 1200 E. Mermaid Lane, Philadelphia 18, Pa. The general-purpose model H-21A oscilloscope displays 2 independent signals on the face of a single 5-in. cathode-ray tube. Each of the 2 channels has individually controlled intensity, focus, and positioning of x and y axes; both input signals can be observed on a common time base or on separate time bases. Sweep circuits, with range of

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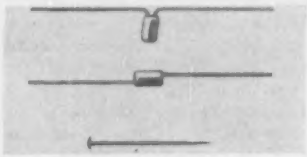
2–50,000 cps, can be triggered externally with a delay of less than 1 μsec; internal or external synchronization may be used. Wide-band, high-gain d-c amplifiers are provided for the horizontal and vertical axes. A built-in, direct-reading calibrator supplies a 60-cycle square wave to either vertical-axis amplifier. A panel voltmeter indicates continuous calibration voltage from 0 to 1.5 volts peak-to-peak; range is governed by a built-in attenuator permitting measurement up to 150 volts peak-to-peak.



Selenium Diodes

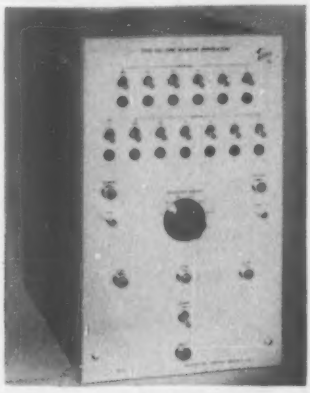
International Rectifier Corp., 1521 E. Grand Ave., El Segundo, Calif. These subminiature selenium diodes, designed for use in an ambient temperature range of −60 to +100° C, are available for outputs of 20, 40, 60, and 80 volts at average currents of 200 μa and 1.5 ma. The 1.5-ma diodes operate satisfactorily under surge-current conditions of 80 ma. Rectifying elements are potted within a thermosetting compound for protection against corrosive atmospheres.

High-Gain D-C Amplifier

George A. Philbrick Researches, Inc., 230 Congress St., Boston 10, Mass. The model K2-W d-c amplifier, designed for feedback computing systems of all speeds, has a gain of 15,000. Input is differential with impedance of over 10 megohms within operating ranges; output range is −50 to +50 volts under loads to 50,000 ohms (within range, impedance is 300 ohms). Rise time is 2 μsec. Power requirements are 5 ma at ±300 volts, d-c.

Gas-Flow Apparatus

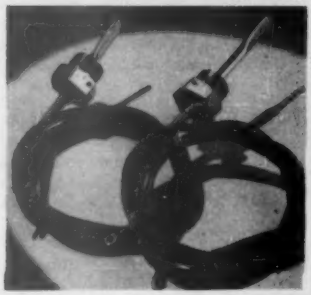
Kahl Scientific Instrument Corp., P. O. Box 1166, El Cajon, Calif. The model 1611 nonmechanical gas-flow-control apparatus regulates flow rate to infinitesimal quantities, indicates pressure changes by means of a self-contained manometer, and may be used as a thermoregulator with a secondary reservoir. Diffusion through a porous ceramic tube is regulated by the height of the mercury column; tubes are provided with different porosities, depending upon the flow rate desired. A stop-cock allows free flow of gas through the by-pass. A mercury reservoir, immersed in solutions being tested, can thermally regulate gas flow by changing mercury column height.



Time-Mark Generator

Tektronix, Inc., P. O. Box 831, Portland 7, Ore. The type 180 time-mark generator, for calibrating such instruments as counters, computers, and oscilloscopes, has time markers of 1, 5, 10, 50, 100, 500 μsec; 1, 5, 10, 50, 100, 500 msec; and 1 sec. The markers are available separately and simultaneously, or mixed in any combination. The unit supplies sine waves of 5, 10, and 50 Mc, and trigger impulses of

1, 10, and 100 cycles, and 1, 10, and 100 kc. All outputs are controlled by a 1-Mc crystal accurate to within 0.02%.



Resistance Thermometers

Trans-Sonics, Inc., Bedford Airport, Bedford, Mass. The type 21 resistance-thermometers are available in ranges of 0–100 to 0–1,000° C, with a resistance change of 50 ohms over the specified range. Temperature response is less than 1 sec in water for 63% of final reading. Accuracy is ±1% of full scale. The platinum-resistor sensing element is encased in stainless steel. Standard pickup-tube length is 2 in.; lengths from 1 in. up can be supplied on special order.

INDUSTRY NOTES

▶**Nuclear Instrument and Chemical Corp.,** 229 W. Erie St., Chicago 10, Ill., has named William B. Johnson Eastern manager. His headquarters is Nuclear Instrument and Chemical Corp., Empire State Building, New York 1, N. Y.

▶**El-Tronics, Inc.,** has located its general offices in new quarters at Fifth and Noble Streets, Philadelphia, Pa. Its research and industrial facilities have been expanded by 17,000 square feet.

▶**Beckman Instruments, Inc.,** S. Pasadena, Calif., has started construction on a 20,000-sq-ft building in Mountainside, N. J. It will house Beckman's Eastern sales and service offices and manufacturing facilities for Helipot Corp., a Beckman subsidiary.

▶**Victoreen Instrument Co.,** 3800 Perkins Ave., Cleveland 14, Ohio, has appointed W. R. Hanson plant manager of the instrument division.

▶**Nuclear Research and Development, Inc.,** 1094 Sutter Ave., St. Louis

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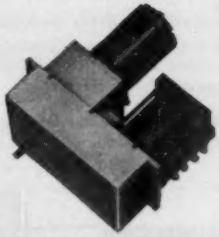

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5, Mo., has opened a branch laboratory and sales office at 33-61 Crescent St., Long Island City, N. Y. The laboratory offers nuclear physics consultation and isotope service.

▶**Vitro Corp. of America,** 233 Broadway, New York 7, N. Y., has promoted R. Carroll Maninger to acting director of the physical research and development department.

▶**Magnetic Research Corp.,** 318 Kansas St., El Segundo, Calif., has been organized for research, development and production of magnetic devices, including amplifiers, voltage regulators, pulse generators, and signal converters.

▶**Walter Kidde Nuclear Laboratories,** 140 Cedar St., New York 6, N. Y., has established laboratory facilities at 975 Stewart Ave., Garden City, N. Y., for research in chemistry, physics, metallurgy, radiochemistry, and materials testing.

▶**Servotrol Co.,** 114 W. Illinois St., Chicago, Ill., under license agreement with Technology Instrument Corp., has entered the field of precision potentiometers and servo components.

▶**Consolidated Engineering Corp.,** 300 N. Sierra Madre Villa, Pasadena 8, Calif., is negotiating for the purchase of the vacuum-equipment-manufacturing portion of Eastman Kodak Company's Distillation Products Industries division. A new plant will be built in Rochester.

LITERATURE AVAILABLE

Potentiometers. Bulletin describes line of unitized precision potentiometers. *Servotrol Co., 114 W. Illinois St., Chicago 10, Ill.*

Vapor detector. Bulletin describes the Microsensor—a color comparator for detecting and measuring microquantities of gaseous material. *Vitro Corp. of America, 233 Broadway, New York 7, N. Y.*

High-vacuum lubricants. This bulletin lists Apiezon greases, and waxes used as high-vacuum equipment lubricants and sealing mediums. *Shell Oil Co., New York 20, N. Y.*

Fixed-ratio speed changers. Bulletin 100 describes miniature fixed-ratio speed changers for servomechanisms, controls, and regulators. *Metron Instrument Co., 432 Lincoln St., Denver 9, Colo.*

Nuclear instruments. Catalog describes nuclear instruments, accessories, and services. *Nucleonic Corp. of America, 497 Union St., Brooklyn 31, N. Y.*

Tachometers. Bulletin describes line of recording and indicating electric tachometers. *Bristol Co., Waterbury 20, Conn.*

Direct-recording equipment. Booklet describes equipment for study and recording of electrical and mechanical phenomena. *Sanborn Co., 38 Osborne St., Cambridge, Mass.*

Voltage stabilizers. Bulletin GEA-5754 explains operation principles and gives specifications of automatic voltage stabilizers. *General Electric Co., Schenectady 5, N. Y.*

Solenoid valves. Bulletin describes improved Atkomatic electrically operated valves. *Atkomatic Valve Co., 545 W. Abbott St., Indianapolis, Ind.*

Nuclear instrumentation. Price list No. 12 includes complete nuclear reactor instrumentation. *Radiation Counter Laboratories, Inc., 5122 W. Grove St., Skokie, Ill.*

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This is a new general-purpose scaling unit, comprising two high-speed electronic decades followed by a resettable electro-mechanical register and incorporating pulse height discrimination and paralysis facilities.

The overall counting speed of the scaler is limited by the mechanical register to about 1000 per second but can be improved by the use of an external high-speed register. Alternatively, scalers can be connected in series when evenly spaced pulses are counted up to 600,000 per second.

The new Ekco Scaler Type N526 is developed from the 1009 unit which it replaces.

SPECIFICATION

Sensitivity. The minimum pulse amplitude is 5 volts positive. The minimum operating pulse width is 0.25 microseconds with a minimum interval of 1.5 microseconds between pulses.

Discrimination. The discriminator permits only those pulses whose amplitude exceeds the pre-set level to be counted. The level can be set at any voltage from 5 to 50.

Paralysis. The Scaler can be rendered inoperative for pre-determined periods between 5 microseconds and 10 milliseconds after receipt of an operating pulse.

Stability. Mains variations up to ± 10% have no effect on the working of the equipment.

Built-in Test Facilities. Internal signals are provided at both the mains frequency and at approximately 3 cycles per second. These can be used for visually checking the timing sequence and also for providing a rough check on the functioning of the discriminator circuit.

External Power Supplies. Provision is made to supply power for operating an external quench unit or scintillation counter amplifier.

Mains Input. 100-120 volts and 200-250 volts, 40-100 c/s.

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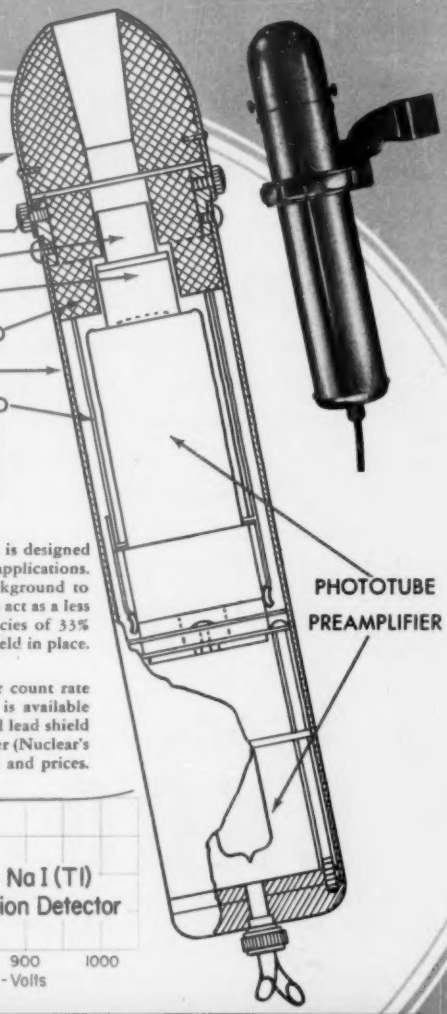
ANOTHER

New nuclear INSTRUMENT

Model DS-1
DIRECTIONAL SCINTILLATION DETECTOR



Sensitive Model DS-1 in lead shield and sample holder will detect gamma radiation of 10^{-10} Curies activity in urine and blood samples, and allow tracer amounts of gamma emitters to be used in metabolism and other studies without serious radiation hazard.

NUCLEAR'S versatile Model DS-1 Scintillation Detector is designed for efficient gamma counting in clinical and laboratory applications. Shielding is arranged to provide excellent ratios of background to source counts when used with the directional shield, or to act as a less directional detector when this shield is removed. Efficiencies of 33% or greater are obtainable using Co^{60} with the external shield in place. Plateau length of the Model DS-1 is 200 volts or more.

Model DS-1 can be used with almost any G-M scaler or count rate meter, since its output pulse is greater than .25 volt. It is available separately as an extremely sensitive detector, with a special lead shield for sample counting, or as part of a mobile count rate meter (Nuclear's "Isotron") for clinical applications. Write for information and prices.

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235 West Erie Street
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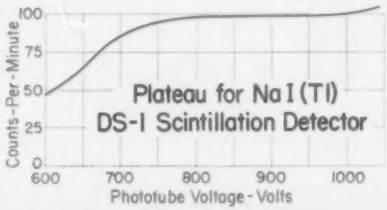

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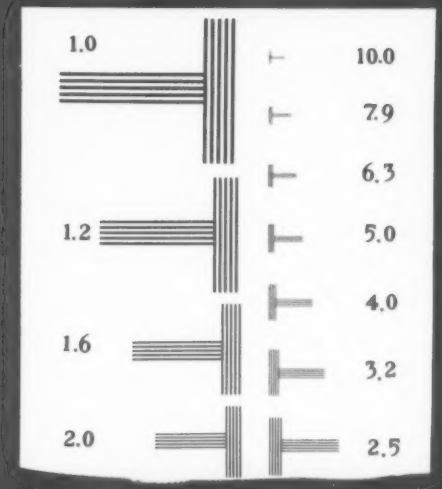
RESOLUTION CHART



100 MILLIMETERS

INSTRUCTIONS Resolution is expressed in terms of the lines per millimeter recorded by a particular film under specified conditions. Numerals in chart indicate the number of lines per millimeter in adjacent "T-shaped" groupings.

In microfilming, it is necessary to determine the reduction ratio and multiply the number of lines in the chart by this value to find the number of lines recorded by the film. As an aid in determining the reduction ratio, the line above is 100 millimeters in length. Measuring this line in the film image and dividing the length into 100 gives the reduction ratio. Example: the line is 20 mm. long in the film image, and $100/20 = 5$.

Examine "T-shaped" line groupings in the film with microscope, and note the number adjacent to finest lines recorded sharply and distinctly. Multiply this number by the reduction factor to obtain resolving power in lines per millimeter. Example: 7.9 group of lines is clearly recorded while lines in the 10.0 group are not distinctly separated. Reduction ratio is 5, and $7.9 \times 5 = 39.5$ lines per millimeter recorded satisfactorily. $10.0 \times 5 = 50$ lines per millimeter which are not recorded satisfactorily. Under the particular conditions, maximum resolution is between 39.5 and 50 lines per millimeter.

Resolution, as measured on the film, is a test of the entire photographic system, including lens, exposure, processing, and other factors. These rarely utilize maximum resolution of the film. Vibrations during exposure, lack of critical focus, and exposures yielding very dense negatives are to be avoided.

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